HANDBOOK

Sampling and Assessing Deposition of Insecticide Sprays Released Over Forests

compiled by

John W. Barry
George P. Markin
Robert B. Ekblad

April 1977

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USDA FOREST SERVICE, FOREST INSECT AND DISEASE MANAGEMENT, METHODS APPLICATION GROUP

USDA EXPANDED DOUGLAS-FIR TUSSOCK MOTH RESEARCH AND DEVELOPMENT PROGRAM

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ABSTRACT

This handbook provides user information on sampling and assessing deposition of insecticide sprays released over forested terrain. The contents consist of a composite of papers organized to introduce and describe field needs for data and the tools available to collect and assess the data. The handbook is written for field use and provides descriptions of samplers for spray deposit sampling, field handling procedures, and assessment methods. The presentation is oriented toward research, pilot, and operational projects. This handbook is also intended to be used as a guide in planning and designing field tests. An appendix is included which provides sources of information, materials, and services and essential reference data.

John W. Barry
USDA Forest Service
Methods Application Group
Davis, California

George P. Markin
USDA Forest Service
Pacific Southwest Forest and Range Experiment Station
Davis, California

Robert B. Ekblad
USDA Forest Service
Missoula Equipment Development Center
Fort Missoula
Missoula, Montana

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife -- if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

PREFACE

This handbook was prepared in response to requests for methods and procedures for sampling and assessing insecticide sprays. Numerous methods and procedures have been used since the advent of aerial application of pesticides, seldom, however, have they been described or publicized. Each applicator has developed his own operational procedures and a degree of sophistication commensurate with his needs and his understanding of the tools and methods available. But because of demands for more efficient and safer application and the increasing need for spray accountability, it is imperative that advances be made available to those who conduct operations involving application of insecticides. Also, there is a need for easy comparison of test results and performance of aircraft spray systems. This can be accomplished by adoption and use of standardized procedures. Spray deposit sample data provide a documentation so successes can be repeated and failures avoided.

As environmental constraints regarding the application of pesticides become more restrictive, the resource manager will be under increasing pressure to account for all toxic and potentially toxic materials discharged into the atmosphere. Methods and techniques for accountability are available.

The Spray Deposit Assessment Workshop at Davis, California, March 16-18, 1976, sponsored by three groups--the USDA Forest Service, Forest Insect and Disease Management, Methods Application Group; USDA Expanded Douglas-fir Tussock Moth Research and Development Program; and the USDA Expanded Gypsy Moth Research and Development Program--provided an opportunity for scientists and engineers to present current information relative to spray deposit sampling and assessment. Appropriate papers and comments from the workshop have been incorporated into this handbook.

The authors wish to acknowledge the support and contributions of Dennis Neill, Jerald E. Dewey, and Kenneth Wright, USDA/DFTM R&D Program; William M. Ciesla, Methods Application Group; Thomas McIntyre, USDA Gypsy Moth Program; and the contributors who are recognized throughout the handbook. Contributors to the Spray Deposit Workshop are acknowledged as follows: Norman B. Akesson, University of California, Davis; Jack Armstrong, Canadian Chemical Research Institute; John Barry, USFS-FI&DM Methods Application Group; Wayne Bousfield, USFS R-1; John Chansler, USFS Northeastern Area; William M. Ciesla, USFS-FI&DM Methods Application Group; R. E. Cowden, University of California, Davis; A. J. Culver, EPA; Jerald E. Dewey, USDA/DFTM R&D Program; Robert B. Ekblad, USFS MEDC; Archie Geiser, USDA APHIS; Jack Henderson, USDA APHIS; Chester Himel, University of Georgia, Athens; Fred Honing, WO-FI&DM; Kaye Johnson, Los Alamos Scientific Laboratory; Bohdan Maksymiuk, USFS PNW; George Markin, USFS PSW; Jack Mounts, USFS R-6; Thomas McIntyre, USFS/Gypsy Moth R&D Program; John Neisess, USFS PNW; Bryan Partridge, Cambridge Instrument Company; Pat Shea, USFS PSW; Ted Slack, Natural Aeronautical Establishment, National Research Council, Canada; Richard Waite, USDA/DFTM R&D Program; Wesley E. Yates, University of California, Davis; Bob Young, USFS-FI&DM Methods Application Group.

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Introduction

by JOHN W. BARRY

PURPOSE

The purpose of the handbook is to provide easy to follow and proven procedures for field personnel who sample and assess aerially applied insecticide.

IMPLEMENTATION

Implementation of the procedures will require training in the form of workshops or field exercises. This handbook provides instructions, guidance and information. The procedures and methods outlined range from general to specific. This is not a manual in the sense that the procedures and methods are inflexible. The handbook provides basic information for the user in developing his plans. There are situations, however, which must be followed as indicated if a specific answer is required. One such situation is the input to a computer program for specific data output relative to accountability of the spray volume recovered on a deposit card.

SCOPE

These procedures and methods have been proven effective and relatively simple to follow under field and laboratory conditions. In a few cases, new methods have been included which have not had the benefit of a long period of field use. For the latter, we anticipate that improvements will be implemented as a use-history is developed. Procedures within this handbook are primarily for aerial application of liquid pesticides to forests.

The handbook covers spray deposit sampling and assessment for field experiments, pilot control projects, and operational control projects. The user will find a complete set of procedures for each project. Because many of the described methods apply to all three types of projects, some redundancy can be expected.

Sampling and assessing of spray drift is beyond the scope of this handbook, although the subject of spray drift is mentioned as it pertains to the subject under discussion. The entire area of spray drift management is a subject of immense importance which will be treated in another publication. The data base of the material in this handbook was obtained primarily from experimental and operational projects in the Northwestern and Northeastern United States.

FORMAT

This handbook is divided into eight sections and an appendix. Each section consists of two or more chapters. Sections I through IV are primarily introductory and descriptive; Sections V through VII deal with field and laboratory procedures; and Section VIII discusses analysis and reports data. Wherever possible and appropriate, individual contributors are indicated. Additional details required by the reader may be obtained from the contributor whose address is provided in the appendix or through the literature citation section.

SECTION II

Data Requirements

RESEARCH FIELD EXPERIMENTS

George P. Markin

Since the objectives of each field experiment are different, spray deposit assessment will also differ to meet these objectives. To outline a standard set of requirements for deposit assessment for research is therefore impossible. From an overall view of the different types of field experiments conducted in the past and the associated types of deposit assessment data collected, six uses of spray deposit assessment can be identified. These uses are listed below and will be discussed by types of information required and the procedures or techniques used.

CALIBRATION

Frequently a researcher involved in application of pesticides is asked to help evaluate new types of aircraft or spray systems used for spraying. The information usually wanted is how wide a swath the new system will produce, what will be the distribution of the spray within the swath, and what average size and range of droplet size can be expected. The standard procedure is to set out a line of recovery surfaces, usually Kromekote® cards, to the line of flight (which ideally should be dead upwind) and extending to either side of the line of flight by at least twice the expected swath width of the system. A dye or other marking material is added to the spray, and the aircraft makes a pass over the center of the line of cards at a predetermined height and speed. After a pass, the cards are picked up; and from the number of spots in a given area (number/cm^2) for each card, the distribution of the spray reaching the ground across the sampling line can be plotted. This information can be used to determine the overall swath of the aircraft as well as the recommended working swath and to indicate irregularities in the pattern reaching the ground which may necessitate changing the location of the spray nozzles on the aircraft.

If a new piece of equipment is being tested, information is often desired on the average droplet size and uniformity of range of droplet sizes produced. From a visual reading of the cards (D-Max method) or from a reading with the aid of a Quantimet® (see section VII), the average size of the droplets expressed as VMD (volume median diameter) can be determined. Determining the range and uniformity of the spray droplets produced is more difficult; usually the size of each droplet counted is determined and placed in a specific size category, i.e., 1-10, 10-20, 20-30 μm, etc. Once the total number of droplets in each category is known, the combined volume of all droplets in that category is determined and this information is plotted for droplet size over a percent cumulative volume. The slope of this line can then be determined mathematically.

RECOVERY

Questions frequently asked during the aerial application are: How much of the material leaving the aircraft actually reaches the target area? and Was the active ingredient deactivated before it reached the ground? Many things can happen to the spray after it leaves the nozzle of the aircraft. Various amounts may evaporate, decreasing the size of the droplets. Oxygen, sunlight, and ultraviolet light may affect some insecticides. The normal method of determining rates of evaporation is to apply an accurately known amount of spray to an open area and then, from cards or plates, determine how much was recovered on the ground. In theory, the difference between the amount of material recovered and the amount of material applied represents that which was lost. Deactivation of chemicals can be studied by the addition of a known amount of insecticide to the spray; then, from chemical analysis, how much was recovered at the target area can be determined. Similarly with microbials, the procedure would be to apply a known number of microbes and determine the number that were recovered at the target area by bioassay.

SPRAY REACHING THE TARGET AREA

Since the usual objective in most field experiments is to kill a population of a pest insect, it is often of interest to the researcher to know in what form (i.e., droplet size) the spray is reaching an individual target insect and how much active material is reaching the insect. This type of information is often used to correlate the mortality of the insect with the number of droplets, the size of the droplets, or the amount of active ingredient impinging upon them. The procedure usually consists of adding a tracer material to the spray, either a dye or a fluorescent particle, and then collecting the individual insects. The amount of insecticide is determined by counting the number of spots or particles on the insects or by washing the insects and analyzing the wash solution to determine the volume of spray that reached them. At times, when the researcher wishes to know if an insect in a particular location received any spray, but working with live insects would be too difficult, pseudoinsects consisting of pith-balls, sections of pipe cleaner, glass rods, etc.--each about the same size as the target insect--have been placed in trees, collected after spraying, and examined to determine whether the spray had reached the pseudoinsect.

Some insecticides do not kill insects directly by landing on them but rather are ingested when the insects eat sprayed foliage. This group of insecticides has become very important in recent years and includes systemics, growth-regulators, and microbials. Again, the objective of deposit analysis is the same, usually to determine if the spray reached the foliage and to correlate different degrees of mortality with different levels of spray deposit. Procedures consist of collecting the foliage and analyzing it with a gas chromatograph to determine active ingredient of material in it, counting the number of spray droplets on a needle or leaf, or bioassaying. Results are usually expressed in micrograms of insecticide per gram of foliage, per square centimeter, per needle, etc.

DESCRIBING THE SPRAY CLOUD

The spray droplets produced by an aircraft usually remain suspended in the air for several seconds, minutes, or even hours before all droplets have descended to the target area. This mass of suspended droplets is usually referred to as the "spray cloud." The physical properties of this spray cloud, i.e., the number of droplets per volume of air, the size of droplets, and the range of droplet sizes, have a direct bearing on the type of coverage and the amount of material deposited at a given point. The size of the droplets in the spray cloud have a direct bearing on how far they will be moved horizontally by low winds before they descend to the ground, whether there is a windowing effect of the different sizes of droplets that reach the ground at a given point, and how far they penetrate into the canopy of the forest.

The most direct method of determining the physical properties of the spray cloud is to collect a volume of air and remove the spray droplets from it. This can be done with Cascade Impactors and rotorrod impellers, devices which physically remove the droplets from a known amount of air as it passes the sampling point. A more passive method consists of the use of spray deposit surfaces such as Kromekote® cards which can be placed in the canopy at different points downwind from the release point. From these spray cards information on the number of droplets per given area (number per cm^2) and size of droplets (vmd) can be determined. These sampling cards can be made into different shapes, cylinders, cones, cubes, etc., and suspended from trees or balloons.

DRIFT

Drift is that portion of the spray cloud which did not reach the ground in the target area but was moved by horizontal winds out of the treatment area. In recent years, drift has become a significant problem in the aerial application of materials. Extensive damage has resulted from the drift of herbicides out of treated areas and into sensitive crops. Contamination of food and water has resulted from insecticides drifting from a treated area into pastures, crops, or watersheds. Unfortunately, the technology for studying drift is poorly developed, but one of the few tools we have is the sampling of spray deposit at points outside the target area. Sampling is usually done by the techniques outlined above but at sample points that are usually selected at sensitive areas, such as streams, lakes, crops, recreation areas, etc. The most important use of drift deposit assessment at this time is to determine whether drift reached a sensitive area in case of subsequent claims of damage.

SPRAY REACHING NONTARGET ANIMALS

When a forested area is treated, many species of animals sensitive to the insecticide being applied may be present. It is frequently of interest to the researcher to determine how much spray is reaching these nontargets and the method by which it is reaching them. If the researcher can determine this information, it is sometimes possible

for him to modify either the method or timing of spray application or the equipment used so the nontargets either are not affected or are minimally affected. The normal method of deposit assessment for nontargets is to take a sample of the animal, water, or soil after spraying and to chemically analyze it to determine the amount of pesticide present. Dyes have also been added to the spray solution for fluorometrical analysis to determine the amount of dye in a water sample or the amount washed from a soil sample. If dyes are used, vertebrates such as birds can be collected after spraying and the number of spray droplets from their feathers counted to determine the amount of exposure. To date, the study of spray deposit associated with nontarget animals has received little attention but will become more important in the future as we try to learn more about the nontarget impact of spraying.

PILOT CONTROL PROJECTS

John W. Barry

Data requirements on pilot control projects are directly related to determining whether the objectives of the project are accomplished. It is absolutely essential that pilot control projects of spray equipment or new spray formulations provide adequate sampling to differentiate between poor execution or equipment failure and ineffectiveness of the spray formulation. An example illustrates this point: An applicator is contracted to apply a new formulation with a proven spray system. Field examination of the ground samplers discloses an erratic coverage or spray pattern on one side of the block and negative coverage on the other side. Further examination of samplers downwind of the spray block shows very heavy coverage. Insect mortality in the block is less than 50 percent. The ground samplers show that this is an inadequate trial. The pilot had either sprayed a nontarget portion of the block or he sprayed under unfavorable meteorological conditions. The ground samplers confirmed that the low insect control is a result of poor execution and not a failure of the spray formulation. If the objective of the pilot control project is strictly to determine if a contract pilot can apply a spray formulation on a spray block to achieve high insect mortality, the ground samplers, supplemented by biological sampling, will provide the answer.

Spray deposit data should be collected and analyzed in a manner comparable to the research test which served as the basis for conducting the pilot control project. If a specific type of sampler was used on the research test to provide data in the field, the same or a similar type should be used on the pilot control project. Generally, sampling should permit the scientist to determine if the pilot control project was in harmony with the research results.

Deposit sampling should be designed to satisfy requirements and data needs as discussed by John Chansler (Anonymous 1976, p. 6-7). Data requirements are summarized as follows:

A. Spray accountability

Determine where the spray was deposited, both within and beyond the spray block.

B. Quality of application

Determine the evenness of the spray, overall coverage, and identity of missed areas.

C. Biological effectiveness

Determine relationships of spray deposit to larval kill, spray deposit to host protection, and spray deposit to population reduction.

D. Physical considerations

Determine influences of topography (i.e., ridges, steep slopes) and meteorological conditions.

E. Predictability

Obtain sufficient operational data from pilot control project to predict spray behavior and insect mortality under operational conditions.

Specific data of primary interest from deposit sampling include:

VMD = Volume or mass median diameter

Droplets = Droplets per square centimeter

Volume = Gallons per acre or hectare

Mass = Ounces per acre and per hectare

With these specific data, items A through E can be examined and evaluated.

OPERATIONAL PROJECTS

John W. Barry

Portions of the discussion of "Pilot Control Projects," apply to operational projects. The primary objective, and frequently the sole objective, in an operational project is to reduce the target insect population to an economically acceptable level. Deposit sampling is operationally oriented to provide the project leader an indication of the overall quality of application.

Overall quality and evenness of application are paramount in an operational project. An even distribution or grid of deposit cards throughout the spray area will provide an indication of relative coverage and an early prediction of success.

Occasionally, intensive sampling similar to that performed on a pilot control project will be necessary. Monitoring of spray deposition in nonspray areas may also be a requirement under certain circumstances.

Deposit samplers placed within spray blocks for the purpose of determining quality of application frequently fail in providing necessary data on operational projects. The cause has primarily been lack of a sampling plan, lack of experience in field handling of cards, selection of improper type of deposit samplers, poor assessment methods, and an insufficient number of samplers. If qualitative data are required, an adequate number of people and man-hours must be available and a solution to the above problems must be found. Results of successful and well-documented pilot control projects with the same spray formulation should provide sufficient data for adequate sampling design.

Spray aircraft characterization trials should be conducted in conjunction with prespray calibration trials to determine effective swath width and volume median diameter measurements of the formulation. detailed procedures for spray aircraft characterization are provided by Dumbauld and Rafferty (1977). On some operational projects, this will be the only spray deposit data requirement.

Spray deposit sampling and assessment *must be well thought out in advance* of the project and kept simple; otherwise experience has shown that the measurements will not be taken.

SECTION III

Samplers for Spray Deposit Assessment

KROMEKOTE® CARDS

George P. Markin

One of the oldest methods of spray deposit assessment used in forest insect spraying is to place paper cards in the area to be sprayed and allow spray droplets to form visible spots on them. In general, this is still the most common method of spray deposit assessment and, in comparison with many other methods, is the cheapest in capital outlay for materials and the easiest in terms of manpower. This method of deposit assessment has the additional advantage that the cards can be examined visually for immediate estimate of coverage while the assessor is still in the field. The cards can also form a permanent record of spray deposit.

White Kromekote® cards are the most commonly used cards (fig. 1). The cards are made from a special high-quality paper which has been treated so that droplets give a uniform spot with sharp, distinct edges. Cards produced before 1970 were sometimes treated on only one side. Pre-1970 cards should be checked to make certain that the treated side is placed up. At present, three different sizes of cards are used in North America. The Canadians use a 4- by 4-inch card; researchers within the USDA Forest Service, USDA Agricultural Research Service, and most universities use a 4- by 5-inch card. Recently, Forest Service, Forest Insect and Disease Management (FIDM), began using a 4-5/16 by 6-5/8-inch card (fig. 1). Use of the cards usually requires that a dye be added to the solution to make the spots visible (a discussion of the types of dye is given in section IV). Certain types of sprays, such as microbials, may contain enough visible material making a dye unnecessary.

A droplet landing on the spray cards spreads out and forms a uniform-size spot with a direct relationship to the size of the droplet forming it. This relationship is referred to as a spread factor. Therefore, by measuring a spot on the card and dividing its diameter by the spread factor, one can determine the size of the droplet forming it (see section VII for discussion of spread factors). By visual or electronic means of reading the cards, one can usually determine both the number of droplets per unit area expressed as number per cm^2 and droplet size expressed as a function of the volume (VMD). From these data, spray volume or mass expressed as gallons per acre or ounces per acre can be determined.

There are two other types of deposit cards, the oil-sensitive card and the Sudan Black card. The former is for oil base sprays and the latter is for some water-base sprays such as Malathion®. Their use is usually limited to qualitative measurements.

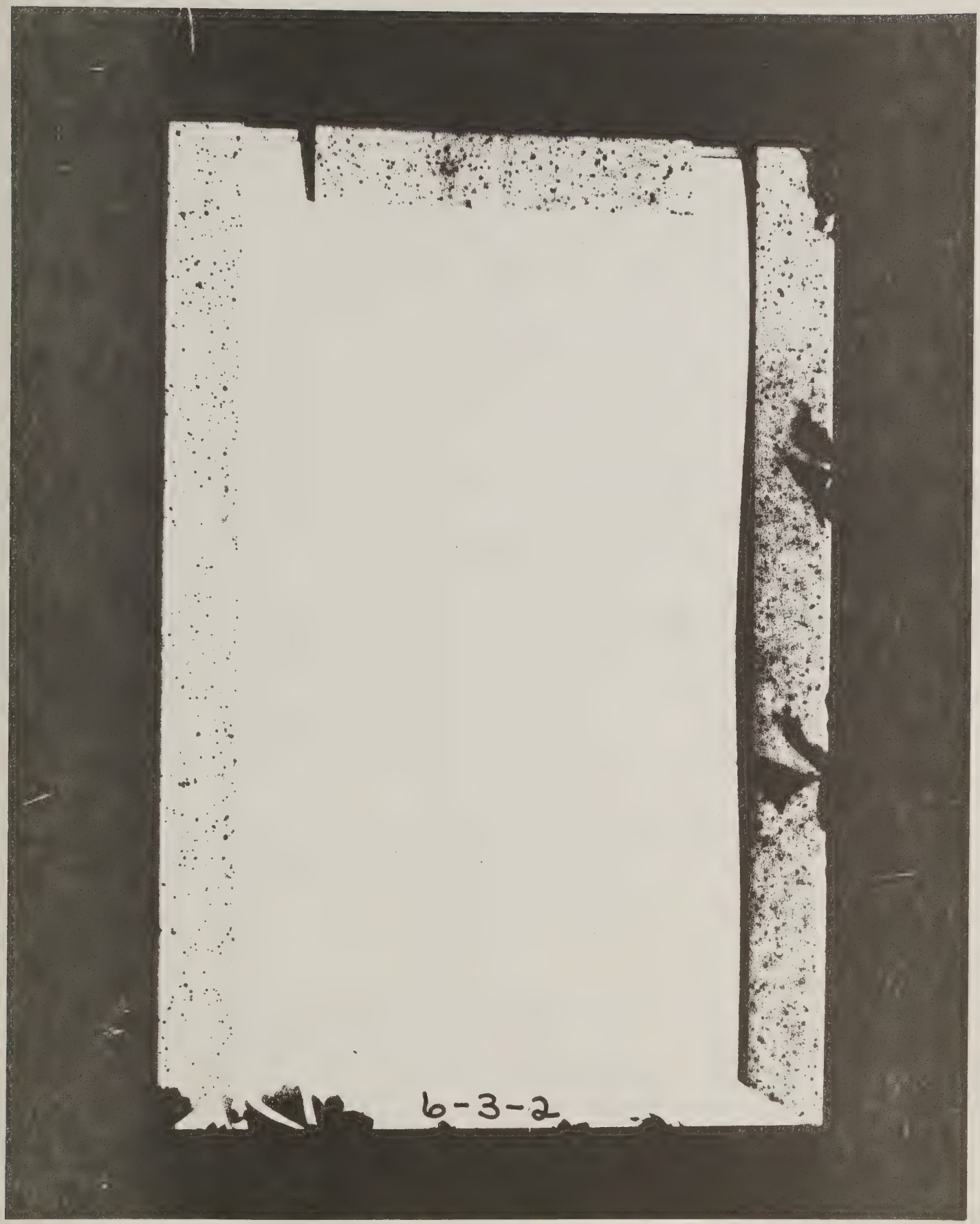


Figure 1.--U.S. Forest Service standard cardholder for 4-5/16 by 6-5/8-inch Kromekote® card properly numbered.

COLLECTION PLATES

George P. Markin

One of the earliest methods of deposit assessment was the use of glass plates placed in an area to be sprayed and then visually examined after spraying to determine if any spray had been deposited (Isler 1963). This method was modified in the early 1950's by the addition of DuPont® oil red dye at the rate of 1 lb/50 gal of diesel fuel, the carrier for the insecticide DDT. The plates were then washed; and the solution was analyzed with a spectrophotometer. By the mid-1950's, the glass plates had been replaced with aluminum collection plates. By the middle 1960's, a fluorescing dye was being used and the wash solutions were analyzed with a fluorometer (Yates and Akesson 1963).

In the 1950's and 1960's, the use of collection plates was mostly restricted to research programs in which the extra time and effort of placing the heavy plates and the time-consuming job of analyzing them was deemed worthwhile. At that time, most assessment work in operational conditions was done with Kromekote® cards, usually the oil-sensitive ones. The collection plates, however, were the standards against which field collected oil-sensitive cards could be compared. To define standards, a collection plate and Kromekote® card were placed side by side in an open area and then treated with different volumes of spray dropped from an airplane. After the volume of spray from the collection plate was determined, the same volume of spray was presumed to have landed on the adjacent card which could then be used as a standard (Davis 1954). In general, the use of aluminum plates was felt to be satisfactory and to give an accurate reading of the volume of spray landing at a given point.

Many of the fluorescing dyes are very sensitive to photodegradation by light. It is generally assumed that fading will be relatively constant on all collection plates. Problems with fading are minimized by retrieving samplers soon after spraying.

PROCEDURE

The normal procedure for using collection plates for spray deposit assessment is to place two plates side by side in the field at the sample point. Before use the plates must be specially cleaned. Cleaning usually consists of a 1-minute soak in a 10-percent solution of Oakite 33®. Plates can also be washed by hand using any cleaning powder. The plates are then rinsed for 1 minute by soaking in distilled water and then finally rinsed in acetone. The rather complicated washing procedure is necessary to remove any grease, dirt, or surface films from the collection plate which might fluoresce and cause the analysis to be incorrect.

Plates are most easily used in pairs and are usually labeled before they are taken into the field. Labels are always placed on the backs of the plates since any writing on the front (where the spray will land) may come off and confuse the analysis. The pairs of plates are left with the two faces together until just before being placed in wire cardholders in the field. Wire cardholders can be like those described by Maksymiuk (1959) or a large spring paper clip mounted on the end of a stiff metal rod. Location of the plates in the field depends on the needs of the researcher (see "Kromekote® Cards" in section III). The plates should be placed in the field immediately preceding spraying and should not be left overnight as dew may collect and disrupt the analysis. After the spraying, the plates should be left out long enough to insure complete settling of spray droplets (30 to 60 minutes). The two plates should be picked up and their sprayed surfaces placed together. The pairs of plates can be stacked together for a plot, wrapped in heavy paper, and returned to the laboratory. One other very critical part of using aluminum plates in the field is the collection of a tank sample of the spray applied to that particular plot. This usually amounts to removing 50 ml of spray, preferably from the aircraft hopper after it has been loaded. The sample should be collected in a brown bottle, sealed, and stored under refrigeration and out of direct light until it can be analyzed.

Aluminum plates provide insecticide mass or volume data for the purpose of determining deposit recovery and the relationship of mass or volume to insect mortality.

FOLIAGE AND INSECTS

John W. Barry

The ultimate spray target is an ideal sampler. For most forest spraying, the target is either the tree foliage or an insect exposed on a leaf. Most foliage assessment methods have dealt primarily with determining total spray mass or volume by chemical analysis. The method also is available which involves counting and sizing droplets directly on the target surfaces. This is especially important in the field when it is necessary to estimate the amount (mass) of spray or the number of droplets reaching the target.

A visible stain on the leaf or needle is necessary for this method. The Rhodamine and Automate Red dyes exhibit a bright stain on conifer needles. Some formulations, even though dyed, do not present an easily detectable stain on the needles. Each spray formulation should be checked for stain detectability in the laboratory prior to a commitment to this technique.

Examination of foliage for stains can produce either qualitative or quantitative data. For qualitative data, the foliage is simply examined with a magnifier for the presence of stains. This field technique will indicate immediately whether the spray reached the intended target; it will also give some indication of relative mass deposit.

Droplets per unit area, such as droplets per needle or square centimeter of needle surface, can be obtained from the number of droplets on a given number of needles. It is important to examine both upper and lower leaf surfaces because smaller droplets will, under some conditions, impact on the lower surface of the leaf.

Droplets can also be sized on the foliage surface. This is accomplished with a dissecting stereo microscope equipped with an eyepiece reticle. This technique is used in research studies such as those involving a determination of which size droplets reached the intended target. Stain size can be converted to aerodynamic droplet size from the amount of spreading that occurs after impact on the leaf surface.

Examination of insects for spray stains has limited application. Droplets of water base sprays dyed with Rhodamine B can be detected on some larvae; however, most oil base sprays do not present a suitable, detectable stain on insects. The use of fluorescent dyes and a microscope equipped with an ultraviolet light source generally is a superior method for examining insects for the presence of spray stains. Solid fluorescent particles as small as 5 micrometers in diameter can be detected and sized on larvae by using an UV light source (Barry et al. 1974, 1977). Examination of spray stains on larvae is basically a research tool suitable for experiments and tests designed to investigate effects of spray droplets on insects.

In summary, spray droplet assessment on foliage provides a rapid field method of assessing the adequacy of coverage. The only require-

ment is use of a suitable dye in the spray formulation. Data including droplets per needle or unit of foliage, droplet size, and spray volume can be obtained by this method. The only instrument required is a magnifying device with a calibrated scale. The details of the method for each formulation and application must be checked prior to field use.

COLLECTION EFFICIENCIES OF SAMPLING SURFACES

Robert B. Ekblad

ARTIFICIAL SURFACES AS DROPLET SAMPLERS

Artificial sampling devices are commonly used in pesticide spray work. A great deal of research and attention has been devoted to the surfaces and tracers that will clearly record the impacted droplets. Much less attention has been given to shape, size, position of the sampler, and windspeed. Unless these factors are considered and correctly chosen, the information gathered may be misleading or incorrectly interpreted.

DEFINITIONS

Terminal Velocity

A droplet that is free to fall in still air will accelerate until its aerodynamic drag is equal to gravitational force, where it will continue to fall at a uniform velocity. The terminal velocity depends on the density and size of the droplet. Some examples are:

Droplet diameter (μm)	Terminal velocity (m/h)
40	0.10
100	.56
150	1.05
250	2.15
400	4.03

Collection Efficiency

As flow of air approaches a sampling surface, it is deflected around the surface. Some of the droplets carried by the air will impact on the sampling surface; others will be deflected around it. The ratio of the number of droplets which impact on the sampling surface to the total number of droplets approaching the sampling surface is the collection efficiency (dynamic catch).

PRINCIPLES

The collection efficiency is affected by (1) shape, size, and position of the sampling surface; (2) density, diameter, and velocity of the droplet; and (3) velocity and direction of the air. The physics and mathematics of these relationships have been developed and, within certain limits, the collection efficiencies can be predicted satisfactorily.

Collection efficiency can be calculated for any shape after certain constants have been established. A cylinder is used for illustration. In figure 2 the flow pattern that air takes around a cylindrical rod is shown. The path of the droplet shown by the dotted line is governed by two forces. The inertia force is described by Newton's first law of motion: "A body will continue in a state of rest or uniform motion in a straight line unless acted upon by an external force." In the absence of air, the droplet will simply continue in a straight line until it impacts on the cylinder. The other force acting on the droplet is the aerodynamic drag (viscous force) which tends to carry the droplet along with the streamline flow of air around the sampler. The final path of the droplet is controlled by a balance of the inertia force and the viscous force. Some droplets will impact and others will miss the sampler.

Some general statements can be made about collection efficiency.

Collection efficiency can be increased by (1) increasing wind velocity, (2) decreasing sampler size, (3) increasing droplet density, and (4) increasing droplet diameter (varies with square of diameter).

Each size droplet has a different collection efficiency for a given sampler.

If fine droplets are deposited uniformly, the collection efficiency is probably high.

Collection efficiency is more difficult to predict for complex shapes.

Larger droplets (300-400 μm) have a different trajectory than small droplets and will not fit the theory exactly.

CYLINDERS

Vertical cylinders have the advantage of uniform collection regardless of wind direction. To avoid end effects, the cylinders should be long compared with their diameters. Cylinders can be made by wrapping cards around a cylindrical form. The deposit will usually be nonuniform, so a complete horizontal segment should be assessed.

Examples of collection efficiencies for a 1/8-inch cylinder are shown in figure 3.

SPHERES

Spheres have the advantage of being completely omnidirectional and can be used to indicate the angle of trajectory. Unfortunately, they cannot be laid flat for automatic scanning nor are there any common spheres available with a smooth fine grain surface. For quick qualitative assessment, ping pong balls can be used.

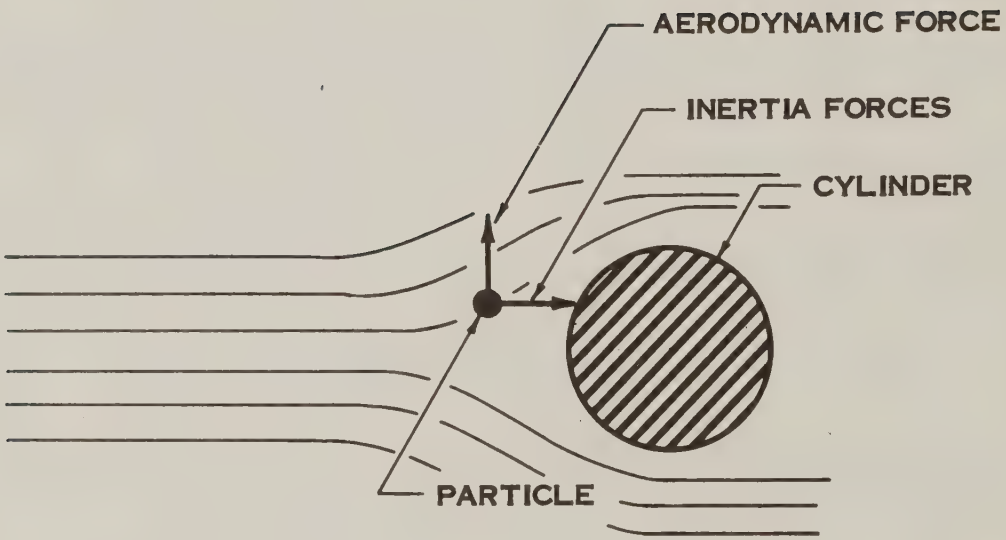


Figure 2.--Flow pattern around a cylinder illustrating relationship between aerodynamic and inertia forces.

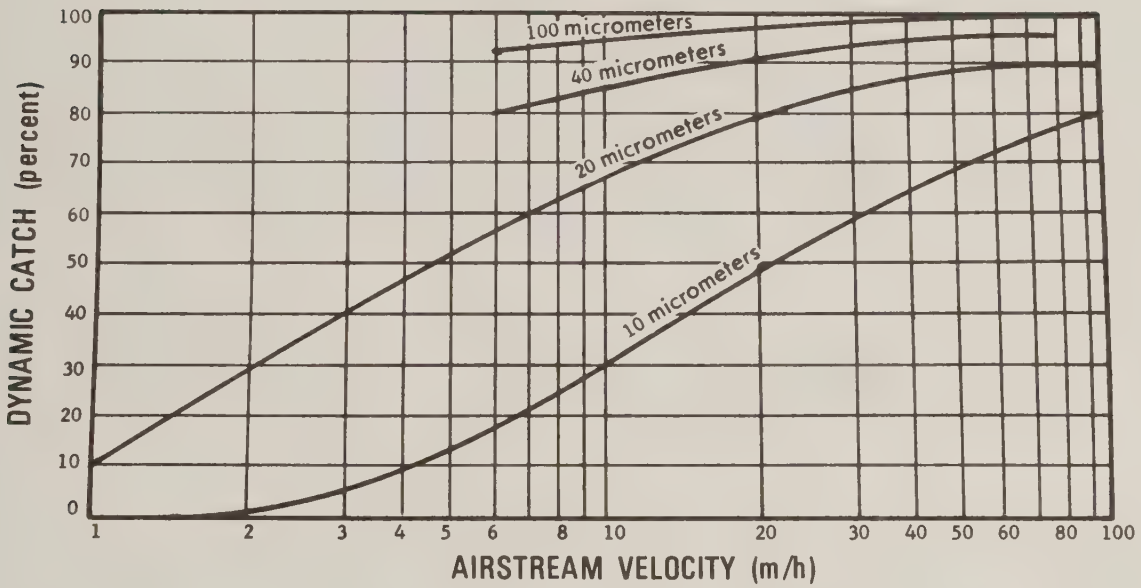


Figure 3.--Dynamic catch of droplets of 10, 20, 40, and 100 micrometers impinging on 1/8-inch diameter cylinder at various airspeeds.

VERTICAL FLAT CARDS

Vertical flat cards must face into the wind. When the cards are placed in the field, the wind direction must be accurately predicted or an array of cards facing in several directions must be used. If a holder is used some edge effects may cause a serious deviation from the predicted efficiencies. If a holder is not used the card may deform which will also change the predicted efficiencies.

BIOLOGICAL SURFACES

The sampling surfaces I have already discussed are ordinarily used to estimate the spray available in the target area; hence, the importance of knowing if they are indeed collecting a representative sample of the spray cloud. Measurements on foliage or insects are usually made as a direct measure of the spray deposited on the target. For this reason we are not usually as interested in their collection efficiencies for estimating a spray cloud, as we are in their function as artificial sampling surfaces.

Biological samplers have a complex geometric shape, and predicting their collection efficiencies is difficult. They may also be moving by their own efforts or fluttering in the wind, which makes them more efficient collectors but harder to predict.

HORIZONTAL FLAT CARDS

Cards placed flat on the ground present a special case of the collection efficiency theory. There can be no vertical wind movement at the ground surface, hence no flow around the card. Collection efficiency is related primarily to the terminal velocity of the droplets and to horizontal windspeed. One study proposes that collection efficiency for horizontal flat plates can be computed by dividing terminal velocity of the droplet by the horizontal windspeed. This method was used for droplets about 30 μm and is valid only up to 0.5 meter per second. At higher speeds the deposition is a result of several mechanisms including turbulence. Fortunately, wind velocities near the ground are usually low.

At low windspeeds horizontal cards placed 18 inches above the ground to avoid vegetative shielding give an estimate similar to mass deposit and vmd ground cards from spray clouds at about 200 vmd. At higher windspeeds the cards should be placed on the ground. Each size droplet exhibits a different collection efficiency. We have seen tests where vertical cylindrical samplers show significant deposit and nearby horizontal ground cards show no deposit.

DISCUSSION

What has been said about sampling surfaces and air movements is limited to the immediate environment of the sampler, and should not be confused with meteorological influences from the aircraft to the target.

Also, this discussion is limited to passive samplers and does not apply directly to aspirated or mechanical samplers.

In summary, one must be aware that:

1. Flat horizontal surfaces near the ground must be used for sampling spray clouds of medium or large droplets in low winds.

2. Vertical cylindrical samplers must be used for sampling spray clouds of medium or fine droplets at elevated heights.

3. Biological samplers give the most accurate target deposition information.

4. Sampling surfaces are selected based on requirements of the user as well as various limitations of handling, cost, etc.; however, when a sampler is selected the user should understand its limitations based on size, shape, position, droplet size, and meteorological conditions.

SECTION IV

Dyes and Tracers

INTRODUCTION

George P. Markin

The exact needs for spray deposit assessment should be fully considered in planning a spray program for research or operational use. Deposit assessment will add to the cost of the program, and some types of assessment are considerably more expensive than others. In particular, the use of a dye is an additional expense and nuisance, since mixing is messy and time consuming. If spray deposit assessment is necessary, the next decision is whether to use a dye or an alternative assessment method. Many materials, such as No. 4 diesel oil or a microbial spray solution containing molasses or sunscreen, are dense and do not need a dye. The spots they leave on ordinary Kromekote® cards are dark enough to be seen or read with electronic counters. Similarly, insecticides such as Dylox®, Sevin®, and Dimilin®, can be assessed against a black background such as construction paper or a photographic negative for assessments which do not require a high degree of sensitivity.

Conversely, if a very high degree of sensitivity is needed, a direct chemical analysis using gas liquid chromotography is recommended. Again, a dye would not be necessary. In a majority of cases where spray deposit assessment is necessary, a dye or some type of tracer material will have to be added to the insecticide spray solution. Some of the most commonly used dyes and tracers are discussed in this section.

OIL BASE CHEMICALS

George P. Markin

The type of dye chosen depends primarily on the method of spray deposit assessment. In general, Rhodamine B Extra Base dye should be used for deposit assessment with a fluorometer. Oil soluble Rhodamine B[1/] Extra Base and Automate Red are also recommended for analysis with a spot counter. Maksymiuk and Moore (1962) reported that Sudan Black dye (2 lb/50 gal of fuel oil No. 2) produced a distinct and easily read spot on Kromekote® cards that may be suitable for analysis by spot counters. The amount of dye per gallon of spray solution depends on the type of spot counter. Generally, the amount of Automate Red is between 0.5 and 2 percent (volume/volume), and for Rhodamine B about 0.1 percent.

The threshold limit of detection of the Quantimet® depends on the lens size area to be scanned and the type of scanning tube used. To preclude any problems in assessing the cards, sample cards with stains representing the spray concentration should be assessed by the group which will process the cards.

[1/] Rhodamine B Extra Base is soluble in only a limited number of solvents, among which diesel and mineral or crop oils are not included. Since these are the common diluents used in forestry spraying, the dye has to be solvated to make it soluble in the solvents. John Neisess (Pacific Northwest Forest and Range Experiment Station) found that by first dissolving the Rhodamine dye at a rate of 151.4 g/gal in oleic acid (a fatty acid) the dye was soluble in any oil solvent. The dye solution is mixed at the rate of 1 qt dye solution per 10 gal total spray mixture or 1 qt is added to every 9.75 gal. When mixing the active ingredient, be sure to allow for the 2.5-percent volume the dye solution will displace. Bioassays of the oleic acid-dye solutions mixed with Dylox® and Sevin® showed the dye solution did not inhibit the activity.

WATER BASE CHEMICALS AND MICROBIALS

John Neisess

Dyes or tracers are commonly added to tank mixes of sprays to facilitate spray deposit assessment. The degree or level of deposit assessment should be considered when the proper dye is chosen for a specific job. Why pay the high cost of a fluorescent dye if the deposit assessment requires that only spray drops collected on Kromekote® cards be counted? A less expensive nonfluorescent dye can be used for such projects.

Fluorescent tracers are used when qualitative and quantitative measurements are needed. Table 1 lists the water base fluorescent dyes that have been tested at the Pacific Northwest Forest and Range Experiment Station. The table includes manufacturer, some light fastness data, estimated cost, and color index (C.I.) name. The C.I. name is a simple reference for any dye and is much like the accepted common name of an insecticide. The light fastness ratings of 1, 2, or 3 correspond to approximately 80-100, 40-80, and 20-40 percent recovery of the dyes after a 1-hour exposure to direct sunlight. Of course, the light fastness of any dye will depend on the thickness of the droplet, the solvent, the dye concentration, and the type of exposure (filtered shade, direct sun, etc.); but a dye with a rating of 1 should be used if possible.

Two dyes which exhibited relatively high light fastness are Brilliant Sulpho Flavine (BSF) and Rhodamine B, with BSF being superior. BSF is a light yellow dye which fluoresces yellow-green. This light color is a disadvantage since the spray droplets can be easily seen only under ultraviolet (UV) light. Bird droppings, pitch, and dust fluoresce at the same wavelengths as BSF, causing confusion in counting or interfering with quantitative assessments. Rhodamine B is a red dye which fluoresces red to red-orange, depending on the solvent. The color of this dye makes the spray deposits readily visible on most collection surfaces. This same bright color becomes a problem if any of the spray gets on the application aircraft. Care should be taken when recovering this dye from foliage samples since chlorophyll fluoresces at the same wavelength. If the solvent removes chlorophyll, inaccurate spray residue values will be recorded.

All dyes should be purchased in the powdered form and stored in a dry place. Many dyes are available as liquid concentrates, but dye crystals will precipitate with storage. If Rhodamine B or BSF is added to the tank mix, they should be added at the rate of 3.785 g of dye per gallon of spray (0.1 percent weight/vol.). This concentration is sufficiently high for fluorometric analysis and, in the case of Rhodamine B, provides enough color to the spray droplets that they can be counted with a Quantimet®. If a nonfluorescent dye, such as Nigrosine OPG, is added to the tank mix, it should be added at the rate of 7.57 g of dye per gallon of spray (0.2 percent weight/vol.). The increased concentration is needed to give the proper contrast to the spray drops on the Kromekote® cards so that they can be counted efficiently by the Quantimet®.

Table 1--*Water-soluble fluorescent dyes*

Dye	Manufacturer	Color index	Light fastness	Estimated cost per pound (1973)
				Dollars
Blancophor SU concentrate	GAF	Flu. Bri.[1/] 25	--	1.00
Brilliant Sulpho Flavine	GAF	Acid yellow 7	1	12.35
Calcofluor White RWP	ACY[2/]	Flu. Bri. 61	3	11.00
Calcofluor White ST	ACY	Flu. Bri. 28	--	.70
Calcozine Rhodamine BX Liquid	ACY	Basic Vio.[3/] 10	--	2.40
DuPont Rhodamine B Extra	DUP[4/]	Basic Vio. 10	1	7.07
DuPont Rhodamine 5 GDN	DUP	Basic red 1	3	--
DuPont Thioflavine TCN	DUP	Basic yellow 1	--	5.70
DuPont Uranine B	DUP	Acid yellow 73	3	3.61
Fluorescein	ACY	Acid yellow 73	3	5.00
Leucophor C-6208	S[5/]	--	--	--
Pontamine White BT	DUP	Flu. Bri. 28	--	.70
Pontamine White SP	DUP	Flu. Bri. 102	--	--
Rhodamine B Extra S	GAF	Basic Vio. 10	1	7.07
Sevron Brilliant Red 3B	DUP	Basic red 15	--	3.00
Sevron Brilliant Red 4G	DUP	Basic red 14	--	3.45
Sevron Orange G	DUP	Basic orange 21	--	3.41
Sevron Yellow L	DUP	Basic yellow 13	--	3.00
Sulpho Rhodamine B. Extra	GAF	--	--	--

[1/] General Analine and Film, fluorescent brilliant.
[2/] American Cyanamid.
[3/] Violet.
[4/] DuPont.
[5/] Sandoz.

When dyes are prepared for a spray project, the dye is weighed into 10- to 100-gallon equivalents, depending on the size of the project. These lots can be packaged in either plastic bags (double bagged) or ice cream cartons. During mixing, the dye generally should be the first additive to the water. The dye should be added while the mix is agitated to insure a complete solution. Some tank mixes may require special mixing; instructions should be provided by the researchers who develop the mixes.

Table 2 lists the dyes and the rates that have been used with the various chemical or microbial insecticides. For the most part, these dyes have been bioassayed with the insecticide being tested against Douglas-fir tussock moth. No inhibitions have been recorded for the recommended rates. Feeding repellencies were noted for high concentrations of all the dyes. Table 2 assumes field experiments require fluoremetric analysis and that operational projects require a less complete deposit assessment analysis. In an operational program where deposit assessment consists only of visual estimates or automated counting of spray droplets on cards, the less expensive nonfluorescent dye should be used.

Table 2--*Recommended dyes and concentrations for various water base insecticides*

Insecticide	Project size[1/]	Dye	Concentration per gallon
			Grams
Biotrol®	FE	Rhodamine B, BSF	3.785
	P,O	Nigrosine	7.57
Dimilin®	FE, P,O	Rhodamine B	3.785
	P,O	Nigrosine	7.57
Dipel®	FE,P	Rhodamine B, BSF	3.785
	O	Nigrosine	7.57
Orthene®	FE,P	Rhodamine B	3.785
	O	Nigrosine	7.57
Thuricide®	FE,P	Rhodamine B, BSF	3.785
	O	Nigrosine	7.57
Douglas-fir tussock moth virus	FE,P	Rhodamine B, BSF	3.785
	O[2/]	None	

[1/] Project sizes: FE = field experiment; P = pilot project; O = operational.

[2/] Assumes Shade® is in the tank mix.

FLUORESCENT PARTICLES

John W. Barry

The use of fluorescent particles (FP) is primarily a research method. Fluorescent particles and tracers are an excellent means for assessing spray particles on target surfaces. This is particularly true in locating and assessing particles that are invisible to the unaided eye.

This technique has been in use for several years in atmospheric diffusion studies and to a limited extent for monitoring pesticides.

The advantage of FP tracers lies in the ability of these particles to fluoresce when excited by ultraviolet light, thus becoming readily visible. This permits examination under lower magnification; and the particles are distinguishable from their background and other foreign matter or nonspray material on insect larvae, foliage, or other target surfaces.

Tracers which fluoresce orange, yellow, and red are the most suitable for this purpose. Fluorescent tracers which fluoresce blue should be avoided because of the high amount of naturally occurring blue fluorescence in the background.

A stereo microscope equipped with a long wave ultraviolet light source is used in this method. The light beam is positioned directly on the object; the room should be dark. Ultraviolet light can cause eye injury; therefore, manufacturers' precautions must be followed.

Three types of fluorescent particles can be used in field tests.

1. Presized particles such as zinc cadium sulfide which fluoresces yellow, green, or red (Himel 1969, Himel and Moore 1967).

2. Oil or water soluble dye dissolved in a suitable diluent and coated on absorbent, presized clay or synthetic particle (Barry et al. 1974). Both types of particles have been used successfully in the field. Particles have been counted on insect larvae and foliage with relative ease by inexperienced personnel using a UV light source and the stereo microscope.

3. Oil and water soluble compounds such as Rhodamine B, which are used to dye spray formulations, will give fluorescence to the spray droplets.

Most fluorescing dyes will fade in sunlight. The amount of fading should be determined for the environmental conditions under which the project will be conducted and the range of limits established. FP is physically stable and fading is not a problem, but FP has a tendency to settle in the tank mix due to density. If an even concentration or homogeneous mix is necessary, the spray mix must be recirculated or agitated continually.

SECTION V

Field Procedures for Deposit Sampling

SAMPLING DESIGN IN EXPERIMENTAL SPRAY BLOCK

John Neisess

The scope of the project dictates the reasons for spray deposit sampling and, therefore, the sampling design. In field experiments, the spray deposit sampling design will be of the highest order and should help determine the relationship between the amount of spray deposited and insect mortality. This is the development phase of design specifications for field sampling. The data will be used in pilot and operational control projects. Therefore, the deposit sampling design used in pilot projects should be an integral part of the design used for field experiments. The design should confirm the specifications developed in the field experiment phase. Deposit sampling designed for operational projects should maintain the specifications developed during the field experiment and pilot control phases.

When a field experiment is being designed, spray deposit sampling should provide information as to why a particular treatment was or was not effective against a designated pest. The ultimate result would be similar to a recipe that would state expected levels of control for various levels of deposit coverage. Deposit coverage could be categorized by such variables as droplet size or droplet size spectra (vmd), droplet density, volume of spray recovered at ground level, or volume or mass of spray recovered in the tree crown. For optimum results of the active ingredient, the ultimate sampling design should sample deposit at or on the surface contacted by the spray. In the Douglas-fir tussock moth and gypsy moth programs, we are fortunate to be working primarily with insecticides that have to be consumed by the larvae. We do not have to worry about how to sample deposits that contact the insect, but instead we need to sample deposits on the foliage eaten by the larvae. It may not be practical to sample foliage in pilot or operational control projects. Consequently, correlations between deposit sampled on foliage and deposit sampled on some other surface should be developed at the field experiment level. With the advent of automatic drop counters such as the Quantimet®, the Kromekote® card should be the other sampling surface. Cards can be subjectively analyzed in the field to determine whether an area has been sprayed and then sent to a laboratory to be completely analyzed by the Quantimet®.

The sampling design most commonly used both in conifer and deciduous forests involves sampling the spray at ground level with aluminum plates and Kromekote® cards and collecting foliage at midcrown level. The ground level sampling station is comprised of two aluminum plates and one card. The plates and cards are held about 2.5 feet above the ground with wire and plastic cardholders. Immediately after the area has been treated, the plates are collected, placed sprayed-face-to-sprayed-face, and stored in slotted boxes until they are analyzed. The cards are collected and stored either with the plastic holders or without them in special boxes. Foliage samples consist of 10-inch branches cut from the midcrown level at the four cardinal directions of each sample tree. These four samples can be bagged (small paper bags) separately or together depending on whether or not the variation in deposit within the tree crown needs to be measured.

Variations in this design depend on the position of the plates and cards. Generally, they are placed in openings adjacent to the sample trees used for population sampling. These openings should be large enough that the sampling station is at least one tree height in distance away from the nearest tree. Maksymiuk (1963a) showed that 70-80 percent loss in deposit recovery results from placing plates and cards within a distance of one tree height. A sample variation of this design or addition to it involves ground level sampling lines within the plot boundaries. These lines are perpendicular to the proposed line of flight of the aircraft. Large openings, roads, etc., are used if available. These open area samplings provide the best estimate of the deposit that reaches the target area (plot at ground level). Deposits collected on the aluminum plates provide data in terms such as gallons per acre. The cards yield drop density and atomization data and data on mass recovery (gallons or ounces per acre). The foliage provides a sampling surface that is an actual part of the insect's environment. The big advantage is that you are sampling the surface that the insect consumes or destroys. Spray droplets on the foliage can be counted to provide density values. The spray residues can be removed by washing with suitable solvents to provide volumes or mass of active ingredient.

Another design, which involves only ground level sampling, places a sampling station of cards and plates in the open, adjacent to each sample tree. One or more sampling stations are placed under each sample tree. The "open" and "under" sampling stations are paired so the difference in deposit should give an estimate of the deposit in the tree crown. This design is dependent on the availability of suitable openings adjacent to the sample tree. The trees will screen part of the spray deposits if the "open" sampling stations are too close to surrounding trees. This results in low estimates of deposit for open areas. If the "open" deposit value is low, the difference, or deposit assumed to be in the trees, will also be low.

Another spray deposit sampling design which has been used involves placing Kromekote® cards under each sample tree at the four cardinal directions. The cards are placed under the tree at the drip line of the tree. Midcrown foliage samples are also collected for each tree at the four cardinal directions. This design allows for sampling the directional differences in deposit at both the ground and midcrown level of each tree. Differential screening ability of the various sample trees may cause poor correlations between deposit data on the ground and at the midcrown.

Sampling designs for pilot control and operational projects can easily be adapted from any of the above experimental designs. Ground level sampling has been used extensively, and if the proper correlations have been developed (fig. 4), there is no reason to include foliage sampling at the pilot control or operational projects level. On the other hand, results of the experimental design may indicate that foliage sampling provides the easiest and most direct method of deposit sampling. If this occurs, the experimental design should be carried through to the pilot control project design.

It would be unwise to try to force a standard sampling design onto all experiments. The designs will vary for different insects,

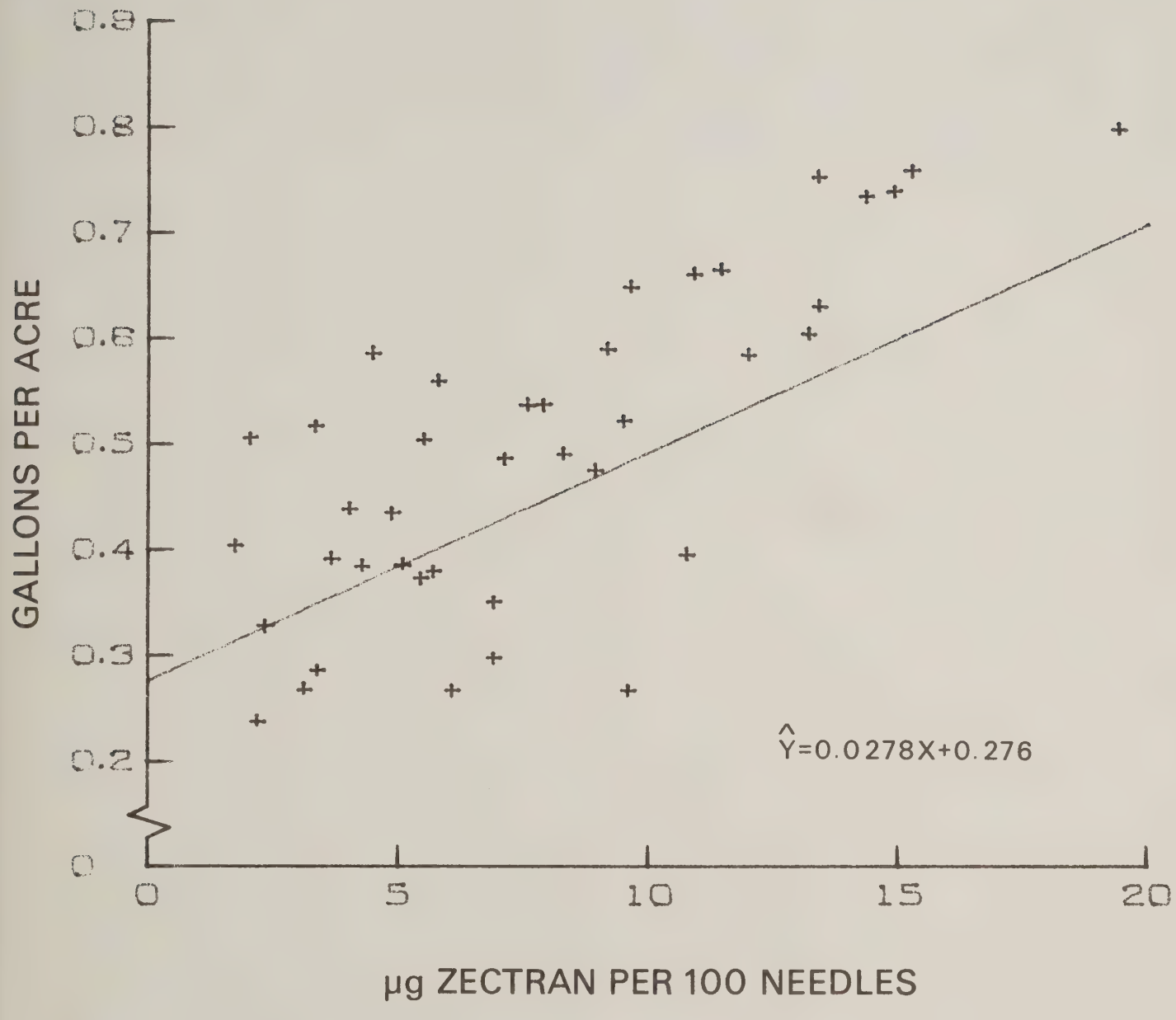


Figure 4.--The relationship between the deposit (gallons per acre) removed from the aluminum plates that were in the open and the deposit recovered from the foliage (µg Zectran/100 needles) of the adjacent trees.

insecticides, host types, and research groups. Some standardization, however, should exist so that the results of different experiments can be compared. The Kromekote® card method is the logical choice for a standard sampling surface because it is easy to use and provides the greatest range of data. Therefore, Kromekote® cards should be an integral part of every deposit sampling design. Although the Kromekote® card method does not approximate the ultimate sampling surface, such as foliage or the actual pest, deposit data collected on cards can be correlated with that from other sampling surfaces (fig. 5). The goal of a good sampling design should provide data that can predict a certain level of mortality resulting from a certain number of droplets of a certain size or mass deposit.

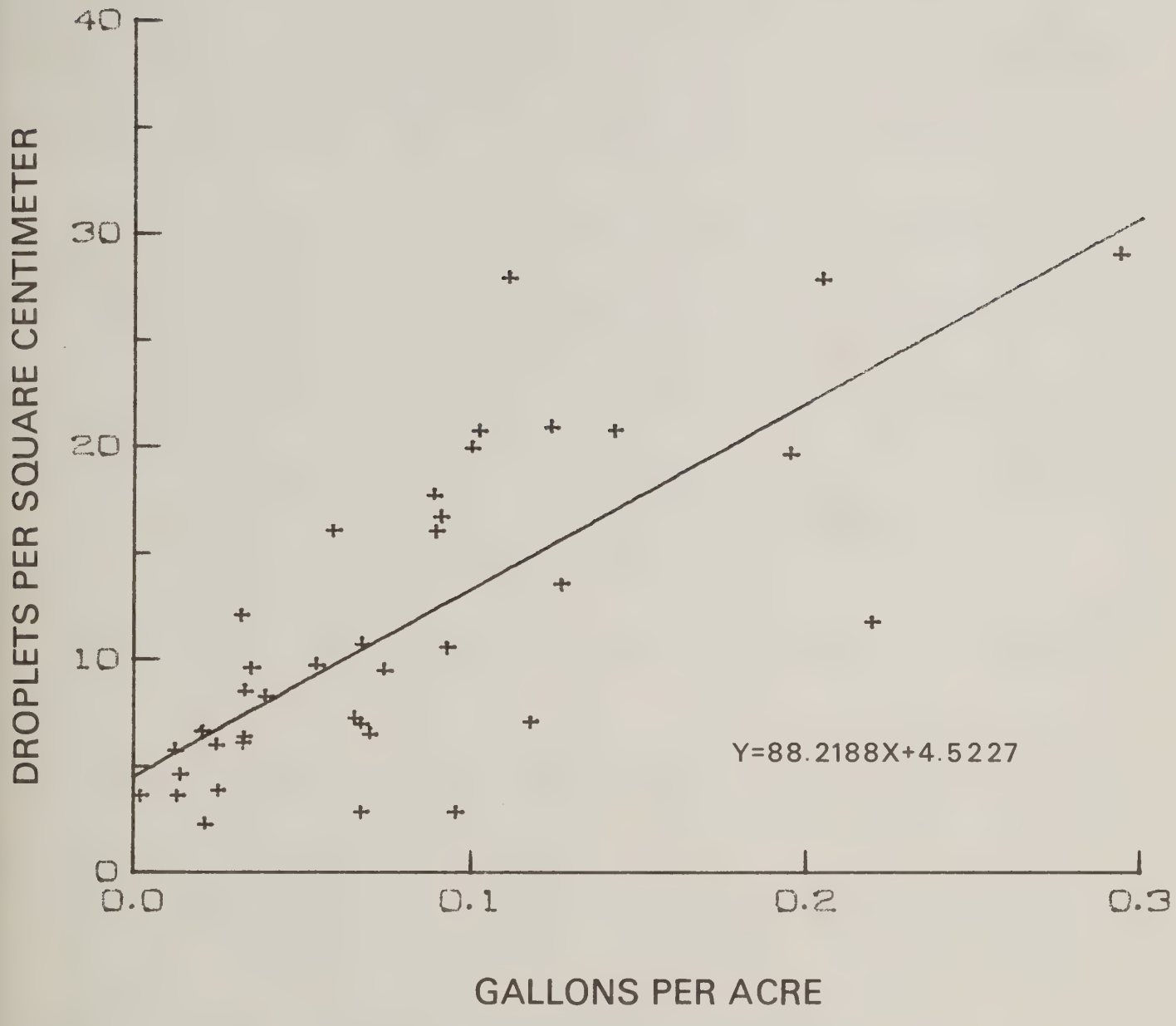


Figure 5.--The association between the drop density (drops/cm^2) and the deposit (gallons per acre) removed from the aluminum plates that were in the open areas.

SAMPLING DESIGN IN PILOT CONTROL AND OPERATIONAL SPRAY BLOCKS

John W. Barry

Various designs have been used to provide spray deposit data on pilot and operational control projects. The data required dictates the design which includes placement, positioning, number, and types of spray deposit cards.

For some projects, such as operational control projects, it is necessary only to determine if the spray reached the target area and if the application was even throughout the spray block. Sampling design for this type of data may be one of random spacing throughout the block or sample lines perpendicular to the swath lines. The total number of cards varies depending on the size of the spray block; however, in the past, 50 to 300 cards have been used on spray blocks ranging from 40 to 6,000 acres. The ideal situation is a grid sampling pattern established within the spray block, but this is seldom practical. Therefore, random spraying or placement of samplers provides the simplest and fastest means of monitoring the quality of spray application. The project director must define, during the project planning stage, the spray deposit data requirements. He should anticipate possible problem areas and plan accordingly.

The project director's specific data requirements can be summarized as follows:

Determine overall quality of spray application.

Monitor spray deposition on nonspray targets within the confines of the spray block.

Account for the spray by determining where the spray was deposited or where it was otherwise depleted by physical decay factors such as evaporation.

Improve application strategy.

Obtain physical data of the spray such as droplet size, droplet density, and spray mass per volume.

Obtain data correlating deposit of spray to insect mortality and tree defoliation.

Support registration of new insecticide formulations.

These specific data requirements can be summarized as follows:

A. Qualitative
   1. Coverage of spray area.
   2. Drift to nontarget areas, streams, roads, buildings, etc.
   3. Coverage of sample trees.

B. Quantitative
   1. Recovery or accountability, on a percent basis, of total material disseminated.
   2. Canopy penetration (ratio of recovery in forest to recovery in the open).
   3. Recovery beneath sample trees as it relates to insect mortality.
   4. Spray characteristics including VMD, droplets per unit area, mass per unit area, etc.

SPRAY DEPOSIT SAMPLING DESIGN

The number of deposit cards in any particular sampling scheme depends on the data required and the size of the spray area. Spacing between sample positions may vary from 20-500 feet except beneath designated trees. The latter often require high sampling density depending on data requirements.

The following is a general guideline for sampling design and density. These are only guidelines. Each situation must be evaluated in terms of project objectives, terrain, logistics, manpower, weather, etc. The design is based primarily on data from pilot control projects.

QUALITATIVE DATA REQUIREMENTS

1. Coverage of spray area: One or two sampling lines should be placed perpendicular to the planned swath lines. Samplers should not be placed directly under trees. Spray recovery on cards will indicate overall coverage.

2. Drift to nontarget or sensitive areas: Placement and number of samplers depends on nature of the sensitive area. If quantitative drift data are required and drift is expected to be light, sensitive samplers should be used.

3. Coverage of sample trees: A single sampler placed in the vicinity of a sample tree is not a good indicator of the deposit reaching that tree because of shielding from nearby trees. Two or more samplers should be used per sample tree to establish coverage.

QUANTITATIVE DATA REQUIREMENTS

1. Recovery or accountability, on a percent basis, of total material disseminated: Total counts or recovery of the spray deposit on any particular group of cards (forest cards, open area cards, etc.) is compared with the application rate as follows:

   Average recovery on cards in an open position is 0.4 gallon per acre. Application rate was 1.0 gallon per acre. Therefore, the recovery or accountability was $\frac{0.4 \text{ gal/acre}}{1.0 \text{ gal/acre}}$ or 40 percent. The validity of the recovery is contingent upon a well-calibrated aircraft, a steady application rate, and a sufficient number of samplers within the sample area.

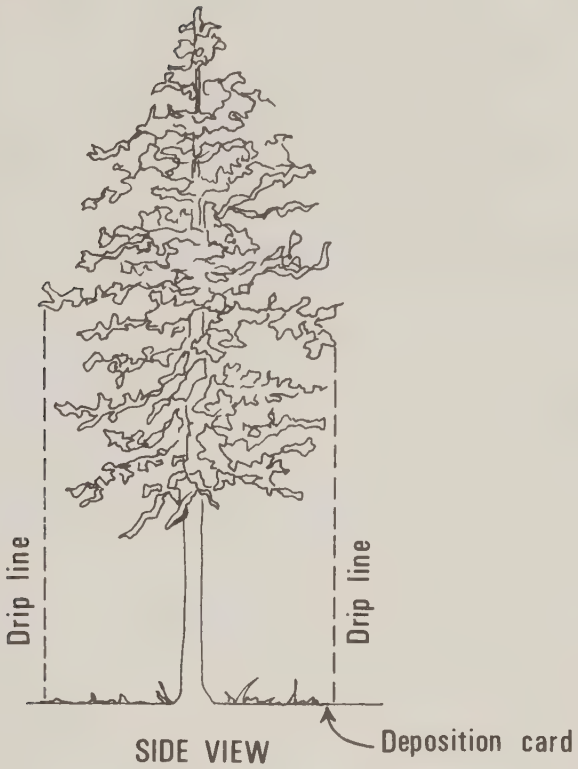
2. Canopy penetration: Canopy penetration is obtained by comparing recovery in the open to recovery in the forest. Number of droplets recovered in the open and those recovered in the forest in each of 16 preselected droplet size categories are plotted and compared. Approximately 50-100 cards should be positioned randomly in the forest and the same number in the open. A good open area should be at least one to two tree heights from the nearest tree. This will allow an unfiltered spray to reach the cards. Canopy penetration is expressed in percent as a ratio; that is, recovery in the forest to recovery in the open. Recovery in the open is assumed to represent what was available at the top of the canopy before the spray penetrated the canopy. Separate ratios are calculated for each droplet size category. The numbers can be obtained from the Automatic Spot Counting and Sizing computer printout described by Luebbe (1977).

3. Recovery beneath sample trees as it relates to insect mortality: It is recommended and often essential to obtain data on spray deposit relative to insect mortality. This provides efficacy and insecticide registration data. The sampling scheme which has proved to be valid for the above purposes is illustrated in figure 6 Four cards should be placed at the drip line of the sample tree, one at each of the four cardinal directions. The cards should be numbered clockwise from the north. Recoveries on each card will vary by wind direction, shielding effect of the sample trees and surrounding trees, and location of the spray swath. Four cards are considered minimum to obtain data for comparing spray deposit with insect mortality; attempts to correlate deposit data to mortality data with fewer than four cards per sample tree have been unsuccessful.

4. Spray characteristics including VMD, droplets per unit area, mass per unit area, etc.: Data of this type are used to determine if previously established spray deposit criteria have been met. They also provide a comparison of one project with another which aids in planning subsequent projects.

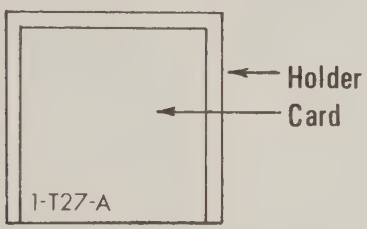
DEPOSITION CARD SAMPLING

TREETOP VIEW



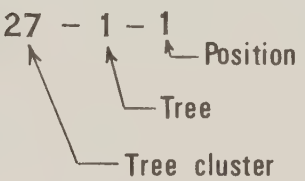
SIDE VIEW

MARKING OF DEPOSITION CARDS

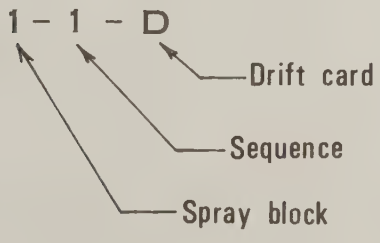


Place marking at bottom margin
¼ inch to ⅜ inch letters

MARKING CODE TREE CARD



MARKING CODE FOR DRIFT CARDS



MARKING CODE FOREST OPEN CARDS

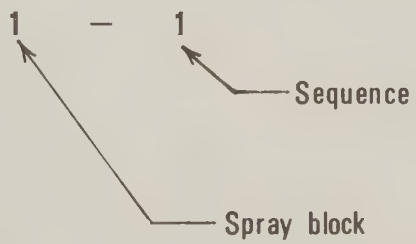


Figure 6.--Deposition card placement and numbering.

AIRCRAFT CHARACTERIZATION
John W. Barry

The methods and procedures presented were extracted from Dumbauld and Rafferty (1976, 1977).

Aircraft characterization involves a determination of the atomization capabilities of an aircraft spray system (aircraft plus the spray device). This includes effective swath width, droplet size spectrum, spray mass or volume, droplet density, and volume median diameter of the spray. Aircraft characterization is discussed because it is tied closely to spray deposit assessment and utilizes the procedures presented in this handbook.

Careful site selection and design of the sampling grid are essential to obtain quality data. Large, cleared, and relatively level areas are ideal for determining spray characteristics. Buildings, trees, powerlines, and other obstructions interfere with the placement of sampling lines, with the windflow field, and with the aircraft flight pattern. Since the card samplers are placed on the ground, high grass or bushes can intercept the droplets before they reach the cards. For this reason, mowing or other means of removing larger plants in the immediate vicinity of the sampling lines may be required. The pilot must maintain level flight for some distance downwind of the sampling line and for even greater distances upwind. A 500-foot rotating sampling platform is available at the Forestry Sciences Laboratory, Corvallis, Oregon. The platform was designed for aircraft characterization and is available for use by Forest Service personnel. Sites where the public can easily gain access should be avoided.

GRID GEOMETRY

An inwind flight trajectory insures that the entire droplet size spectrum of the spray cloud can be sampled with a minimum number of samplers. The grid should be designed so that winds blow across sampling lines. Experienced field meteorologists and test personnel know that specifying a mean wind direction for a short time well in advance of a trial is extremely difficult. Therefore, the sampling grid must be designed to accommodate variations in the mean wind direction to prevent serious errors in the data analysis. For this reason, an equilateral triangle design is recommended. The design tends to limit the angle between the aircraft flightpath (flown into the wind) and a sampling line of 90 ± 30 degrees. The choice of the proper flightpath for any given trial depends, as explained below, on the mean wind direction measurements made just before the trial.

Knowledge of the most frequent wind directions at the site chosen for the trials will assist in orienting the triangular design to further insure that winds blow across sampling lines. Spray projects are normally conducted during the early morning and late evening hours in periods of fair weather. The light wind conditions usually present

during these hours are generally favorable for maximum canopy penetration and minimum drift of the spray material. Strong winds and high levels of atmospheric turbulence generally diminish spray deposition in the immediate target area and increase the possibility of downwind drift. These considerations also apply to the determination of aircraft spray characteristics. Thus, one of the sampling lines should be across the wind directions expected during the early morning or late evening hours. A trained micrometeorologist can often determine expected mean wind directions for these periods from a knowledge of the topographical features in the area.

Length of the Triangle Sides

Each side of the triangular grid array must be long enough to contain the swath width or the contamination density. Complicated diffusion-deposition formulas can be used to determine the length (L) as a function of droplet settling velocity, planned aircraft flight altitude, and meteorological conditions; but experience has shown that multiplying flight height (H) by 10 is normally sufficient to contain the swath width (L=10H). This expression normally guarantees that swath width will be contained. If the aircraft flies at a height of 15 meters (50 ft), the length of each side of the triangle should be 150 meters (500 ft).

Sampler Spacing

The sampler spacing along each side of the triangle must be sufficiently dense that statistically stable estimates of the volume median diameter and other spray characteristics can be obtained. Modeling and field experience show that multiplying aircraft height by 0.4 gives satisfactory spacing ($S = \frac{L}{25} = 0.4H$); where S = maximum sampler separation distance.

Aircraft Height and Spray Line Length

For the purpose of characterizing aircraft spray, it is generally desirable that the aircraft fly as low as possible to minimize sampling grid requirements while satisfying flight safety. A 15-meter (50-ft) minimum altitude generally meets both requirements. The flight altitude may have to be increased, however, if the density of the stains from droplets deposited on the sampling cards is so great that spray characteristics cannot be determined. A simple one-trial experiment at an aircraft altitude of 15 meters can be conducted prior to final specification of the grid design to determine if the cards will be covered so heavily that stains cannot be counted and sized. On the other hand, a length 300 meters can be used in the grid design for a 30-meter aircraft altitude with a sampler separation distance of 6 meters appropriate for an aircraft altitude of 15 meters. If the first trials indicate that a 15-meter altitude results in spray densities that cannot be conveniently counted, the flight altitude can be increased to 30 meters and every other sampling position removed from each side of the triangular grid. Since spray density is nearly inversely proportional to aircraft altitude, an increase in aircraft altitude by a factor of two will reduce deposition density by half.

The length of the inwind release line required to insure that the crosswind mass recovery sampled on the grid is not affected also depends on the aircraft altitude as well as spray characteristics and meteorological conditions. Calculations show that if much of the spray cloud mass is comprised of droplets with diameters of 50 micrometers or less and windspeeds are less than or equal to 4 meters per second, the length of the release line upwind of the sampling grid should be about 100 times the aircraft altitude. If most of the mass of the spray cloud is comprised of droplets between 50 and 100 micrometers in diameter and windspeeds are less than 4 meters per second, the release line length upwind of the sampling grid should be about 70 times the aircraft altitude. Finally, if most of the spray cloud mass is comprised of droplets greater than 100 micrometers in diameter, the release line length upwind of the sampling grid need only be 35 times the aircraft altitude. In every case, the release line must begin at least 50 to 100 meters downwind of the sampling grid. Longer distances may be required to stabilize the aircraft altitude and the flow rate in the spray dissemination system.

DRESSING THE GRID

After the length of the sides of the triangular sampling grid and the grid spacing have been determined, a transit theodolite, or compass, and a manila rope are used to lay out the sampling lines. The manila rope is stretched taut at right angles to the most probable wind direction during the early morning hours. The theodolite insures that the line segment is straight and correctly oriented. Quarter-inch stock metal rods are then driven or forced into the ground at the predetermined sampling intervals marked by the surveyor's tape tacked to the rope. The rope is then used to measure the 60-degree angles and lay out the next two sides of the array. Large wooden stakes, 5 to 6 feet high, marked with bright tape, should be placed at the end of each side of the triangle and at the center position of each side. It may be necessary to clear a small area around each metal rod so that plants or other material do not intercept droplets that would otherwise impact on the card.

Cards for three or more trials can be premarked and placed in cardholders prior to each day's operation. At a minimum, the marks placed on each card should identify the trial (or flight) number, sampling number, and sampler location on the line. For example, the identification 13-1-50 might indicate trial 13, sampling line 1, and the 50th card position of sampling line 1. The cards in their cardholders can be packed in ascending numerical order in wooden boxes for transportation to the field site so that one or two boxes, depending on the length of the sampling line, are sufficient to dress one side of the triangular array. The cardholders should be placed at the side of each stake so that the stake does not intercept droplets which would otherwise strike the card. The cardholder must be placed flat on the ground, and care must be taken that loose soil or dust is not kicked onto the card.

ATMOSPHERIC CONSIDERATIONS AND MEASUREMENTS

John W. Barry

Meteorological data are used for research and operational purposes and are occasionally needed during spray drift and accident investigations.

Meteorology plays a significant role in spray behavior; therefore, spray deposit sampling design and field sampling must incorporate the influence of meteorology.

Basic meteorological measurements should include the following:

Temperature (degrees C):	1 to 2 meters above ground in the open 1 to 2 meters above ground in the forest top of canopy release height
Relative humidity (percent):	2 meters above ground in the open
Wind direction (degrees):	2-meter level in the open top of canopy release height
Windspeed (meter per second):	2-meter level in forest 2-meter level in open top of canopy release height
Temperature gradient (degrees):	2-meter level to top of canopy and at release height
Barometric pressure:	vicinity of spray site
Turbulence:	top of canopy
Surface observations:	cloud cover soil condition (dampness) vegetation condition (dampness) precipitation

These data should be collected continually during the spray operations. If this is not practical because of lack of personnel or adequate equipment, then, as a minimum, data should be collected at the start, midpoint, and end of spraying. Temperature, relative humidity, and precipitation should be measured for the duration of the project.

Uses of meteorological observations include:

Selecting the project site.
Deciding whether or not to spray.
Developing and alternating spray strategy.
Selecting appropriate tables for choosing swath locations.
Comparing project results.
Monitoring of handling and storage of insecticides.
Minimizing spray drift.
Developing spray accountability plan. Postspray reviews may require the project leader to make reasonable estimates of spray loss.
Documenting drift incidents and accidents.

Armstrong (Anonymous 1976, p. 21-22) reported that there is a relationship between spray deposit and temperature above the canopy and windspeed. This relationship is called the stability ratio as described by Yates et al. (1967).

The Forest Service has not implemented a stability ratio model of determining optimum meteorological conditions for spraying to enhance spray deposit on the target.

Forest Service, Insect and Disease Management (FI&DM), plans to publish a meteorological manual for field use. The manual will incorporate all operational considerations related to meteorology and aerial spray projects, including the stability ratio model if it proves suitable for FI&DM use.

When deposit samplers are placed and positioned, the scavenging effect of forests on the spray (depletion) and the nature of the terrain should be considered. Cards placed on the forest floor will receive less spray than those placed in the open. Cards placed on open ridges usually swept by winds will receive little or no spray. Spray droplets fall more in the direction of the wind (fig. 7), not straight down (fig. 8). Sprays released over ridges will be deposited at great distances downwind from the release. If data on spray deposit in the open areas of a spray block are needed, sampling should be conducted in an open area where the influence of topographical features and wind is minimum.

DRAINAGE WIND

Drainage winds are either mountain-valley or slope-valley winds. As the slopes of the valley cool by radiation, the air adjacent to the slopes also cools and becomes more dense than the air at the same elevation over the center of the valley. This dense air drains down the slopes toward the valley axis. The drainage flows from the slopes at various points along the valley combine into a general flow toward the valley mouth.

Although greatly dependent on the slope and configuration of the valley, on the ground cover, and on the prevailing large-scale meteorological situation, down-valley flows of perhaps 5 meters per second are not uncommon. The slope-valley circulation, once established, usually

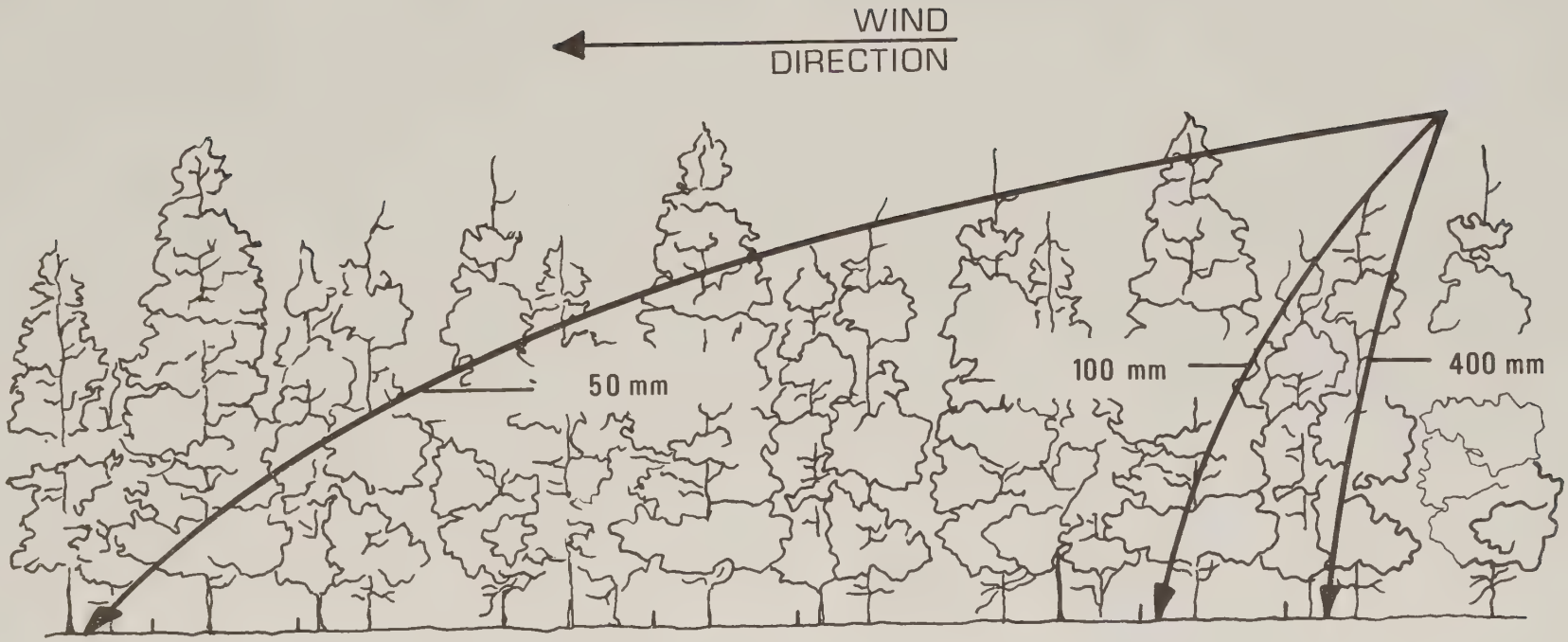


Figure 7.--Relative trajectories of various sized particles penetrating forest as function of windspeed.

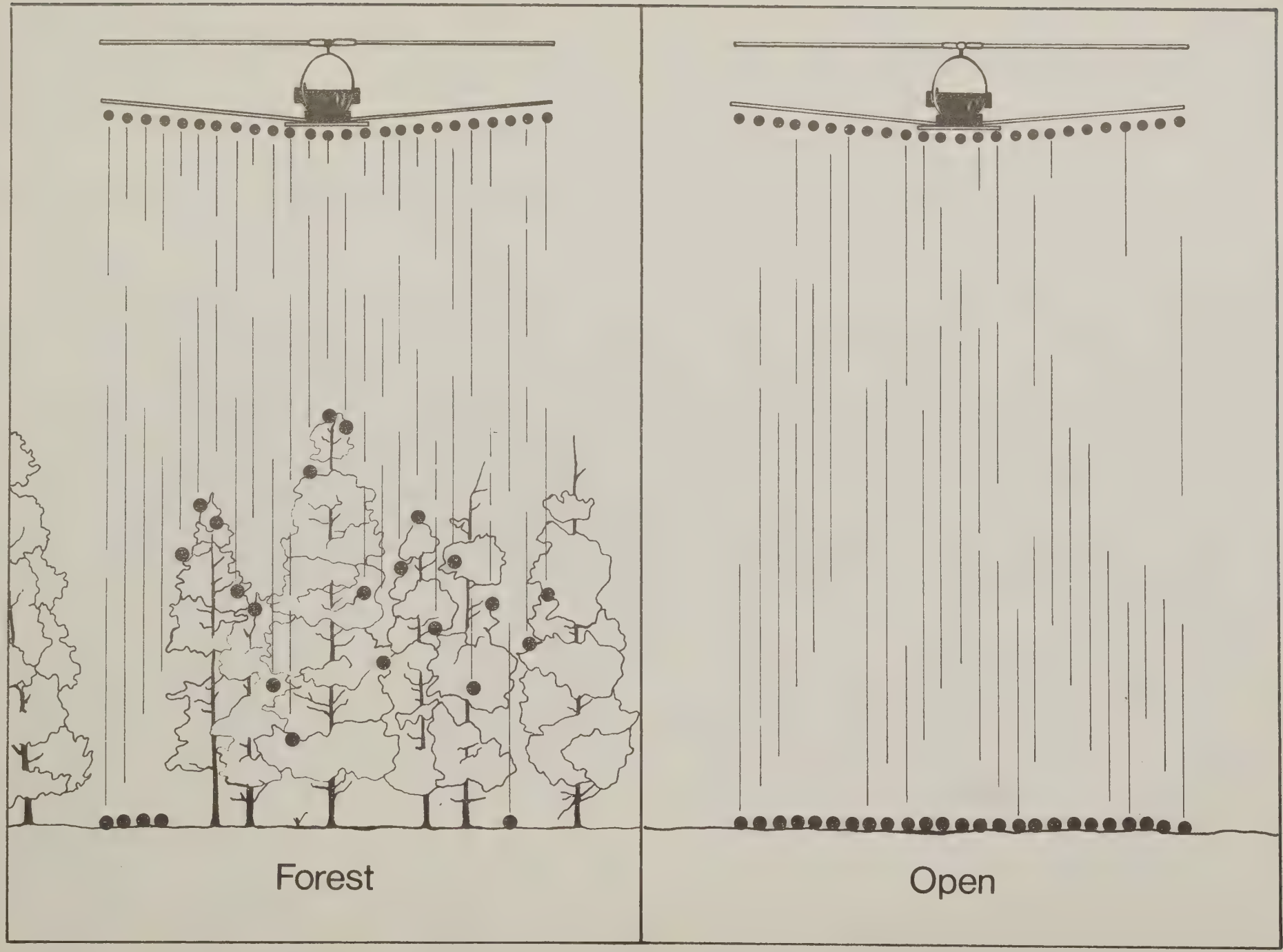


Figure 8.--Capture of droplets by vegetative elements. Penetration ratio, defined as a function of droplet size, is the number of droplets recovered under the canopy to the number of droplets recovered in the open. Spray droplets do not fall straight down; they angle from the vertical depending on windspeed and the velocity of the droplets.

extends to the height of the ridgetops. This pattern is destroyed after sunrise by heat from the slopes and valley floor (Slade 1968); this change is often dramatic and rapid. When the rays of the sun hit the eastern slopes, downslope drainage winds weaken, direction varies, and upslope winds can start within a short time.

On clear days with light winds, an opposite circulation pattern may develop. This upvalley, upslope flow is due to the heating of the air adjacent to the sun-warmed slopes and valley floor. This phenomenon is not as marked as the night flow. At night, turbulence in the valley is suppressed by a thermal inversion; thus, the flow in the valley is comparatively undisturbed. By day, however, the turbulence induced by the heated land surface can be expected to stir the air within the valley and to cause it to mix with the free flow of air above the ridges. This turbulence is generally disruptive, and it hinders establishment of any sensitively balanced circulation patterns. Therefore, although daytime upslope, upvalley patterns undoubtedly exist, they are not so common or so well marked as the downvalley flow at night (Slade 1968).

Spray operations should be completed before the upvalley winds develop fully, although frequently this is not practical. Spray strategy for downslope winds is different from that for upslope winds. These differences will not be discussed in this handbook.

FIELD HANDLING OF DEPOSIT CARDS ON FIELD EXPERIMENTS

George P. Markin

In the field a cardholder holds the card in a horizontal position above the ground at a predetermined level. The elevation above the ground usually ranges from 18 inches to 2 feet and keeps the cards away from moist ground surfaces and small animals and lifts them above underbrush or ground cover which could shade the card. If the underbrush is higher than the cardholder the brush must be cut to prevent the vegetation from intercepting the spray.

Several types of cardholders have been used. The Canadians have developed a system consisting of two aluminum plates hinged together. A card is held to each plate with two rubber bands and placed on top of a wooden stake. When not in use, the two aluminum plates sandwich the cards between them, but the cards do not touch since they are separated by the rubber bands. In the United States a wire cardholder has been used. This often contains a special wire knot at the top that is arranged in such a manner that sections of it slide over and under the card to hold it in place (Maksymiuk 1959). This arrangement has the disadvantage of producing a blank area where the wire intercepts the landing spray droplets. Another arrangement consists of a straight heavy wire with a heavy snap-type paper clip welded to it to hold the card (fig. 9). The cardholder consists of a thin, flat, yellow plastic sheet slightly larger than the Kromekote® card, three edges of which have been folded up and over to form a lip (see fig. 1 in section III).

In general, it is best to place cards just before spraying. Occasionally this means that crews must be on the plots before daylight. Under certain conditions of humidity the cards will absorb moisture from the air. A moist card produces a spot that is not as distinct or sharp edged as a dry card. Such spots have a different spread factor from those on a dry card. Moist cards also have a tendency to warp and retain this warp after they dry. Reading badly warped cards is almost impossible with some of the spot counting devices.

After the aircraft has completed treatment of the area, cards should be left out for approximately 1 hour. This is necessary to allow the very small spray droplets to settle and to allow the spots to dry. Cards should never be left out much longer than 1 hour, particularly if there is a chance that they may be exposed to direct sunlight which will fade some dyes. A special carrier is used by Forest Service researchers to transport cards (fig. 10). Note that the cards must be removed from the holders.

Never handle the surface of the card or allow the surface to become dirty. Oil or dirt can leave a spot that will be misread by the spot counter. It is best to pick up the cards, blow on them or wave them to remove any needles or pollen that has collected and then, if they are dry, place them together in a stack which can be stored in a paper sack. Once in a sack, the cards can be stored for at least 6 months.

Figure 9.--Kromekote® card on metal stake. Note that the card is above the ground cover and parallel to the ground.

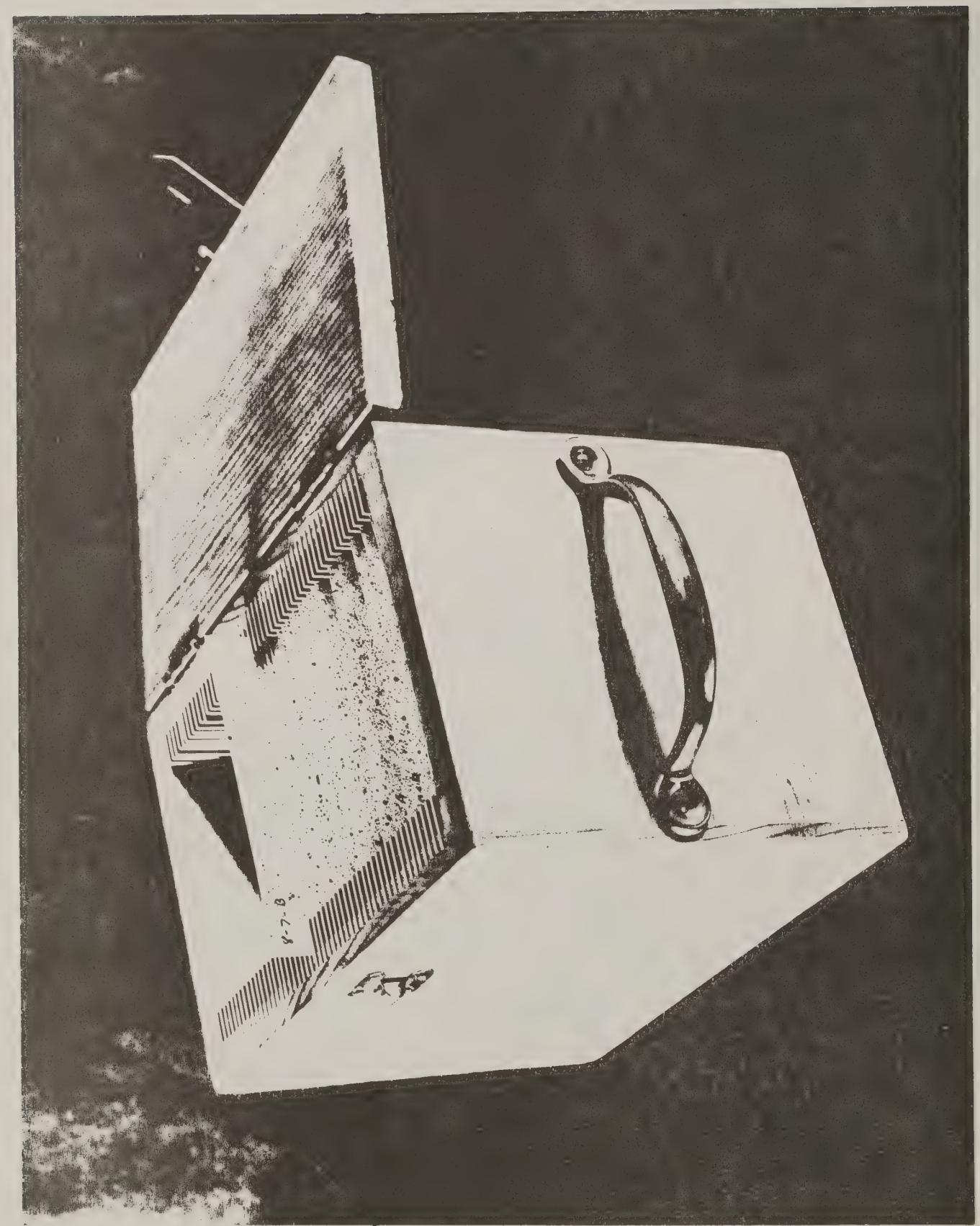


Figure 10.--Carrier for Kromekote® cards without cardholder.

Kromekote® cards are not the only type of card which could be placed out to catch spray. Typing paper, white cardboard, adding machine tape, etc., have been used successfully. The major disadvantages of other types of cards are: (1) they do not give as clearly defined spots as Kromekote® cards do, and (2) we do not know the spread factor that would give the relationship between spot size on the card and size of the droplet that formed it. Determining the spread factor is a long, expensive, and time-consuming procedure; and use of an unknown paper, under the assumption that the spread factor for it can be determined later, is unwise.

A modification of Kromekote® cards in the 1950's and 1960's was a dye sensitive card. The procedure was basically a reversal of the technique described above. The dye is added to the card (Printflex®), and the droplet landing on the card temporarily dissolves the oil, forming a permanent mark or spot. Cards of this type were compared against prepared standards to determine the gallons to use per acre. The disadvantages of dyed cards are: none are sensitive to water-base sprays; they have a tendency to fade in the field; they are messy to handle; and they will not show spots formed by very small spray droplets. The methods of manufacturing and using these cards and the procedure for preparing a set of standards against which they can be compared are described by Davis and Elliott (1953) and White (1959). The Malathion®-sensitive card is a modification of the oil-sensitive card. The procedure is basically the same and consists of dipping Kromekote® cards in a solution of Sudan Black BR dye. Droplets of Malathion® landing on the card produce permanent spots and this type of card is reported to be very sensitive for very small droplets. The technique and instruction for use of these cards is well described by Skoog and Cowan (1958).

With the recent advent of the use of several insecticides consisting of a finely ground powder suspended in a carrier, i.e., Sevin 4®-oil, Dylox®, Dimilin®, etc., black cards can be used. The liquid carrier either evaporates or soaks into the card, leaving a visible spot of white. The technique can use almost any black surface such as construction paper, cardboard, photograph negatives, or black-dyed Kromekote® cards. Because the white stain is a concentration of the insecticide and not a mark made by the oil, a spread factor cannot be determined. This does not allow determination of such values as gallons per acre deposited or volume median diameter. Also, if these cards are collected as permanent records or are carried to a laboratory for analysis, these spots can flake from the card and the record is lost. If such recovery surfaces are used, a slotted box for storing the cards will protect them until they are read.

A disadvantage in use of all types of paper cards is their inefficiency in collecting all spray droplets. Two types of errors in the use of cards in the field can commonly occur. The first is that the carrier in a small droplet may evaporate, concentrating the insecticide into a small dry particle. These particles may reach the ground and be effective in controlling the insect but they do not attach to the cards and are lost when the cards are collected. The second error is that the efficiency of cards for collecting very small droplets changes with wind velocity since a flat card even in very low wind can produce an airstream that deflects fine particles around the card.

FIELD HANDLING OF DEPOSIT CARDS ON PILOT CONTROL AND OPERATIONAL PROJECTS

John W. Barry

Deposit cards are a simple and economical means of sampling which produce both qualitative and quantitative data depending on the type of card used and the spray formulation. Currently, Kromekote® cards (fig. 11) are the standard deposit card sampler. A few simple procedures will insure that the sampling meets its intended purpose.

The key to implementing proper field handling of deposit cards lies with the field foreman. He must be knowledgeable and motivated to demand compliance to instructions from his field crew. Implementation is dependent upon his ability to communicate, organize, supervise, and monitor.

The field foreman is responsible for three elements:

1. Preparation and implementation of field crew instructions.
2. Organizational briefings of field crew before each trial.
3. Supervision and monitoring of performance of the field crew.

The foreman should prepare detailed and explicit instructions for the field crew. These instructions should include the following:

1. Diagram of the spray site.
2. Method and system of marking the samplers and samples.
3. Location where cards are to be picked up and returned.
4. Protection of samples during transit.
5. Positioning and placement of samplers in the field to include diagrams.
6. Protection of samples from sunlight, humidity, rain, dust, etc.
7. Handling of tote or carrying boxes.
8. Checklist of necessary equipment and materials.
9. Special instructions as required.

Briefings of the field crew should be held before each trial. It is essential that the field crew understand the purpose, the test objectives, and any changes in written instructions. The crew will do a better job if they understand the reasons for their efforts. These briefings deal primarily with coordination and communication of project schedules and tasks, and they provide an opportunity to discuss and resolve questions and problems. Briefings also help foster a team spirit.

A staging area is usually appropriate for meetings to organize equipment and materials. Each crew should stage its materials the day before the field operation. This provides an opportunity to examine and account for necessary equipment and materials before the early morning rush.

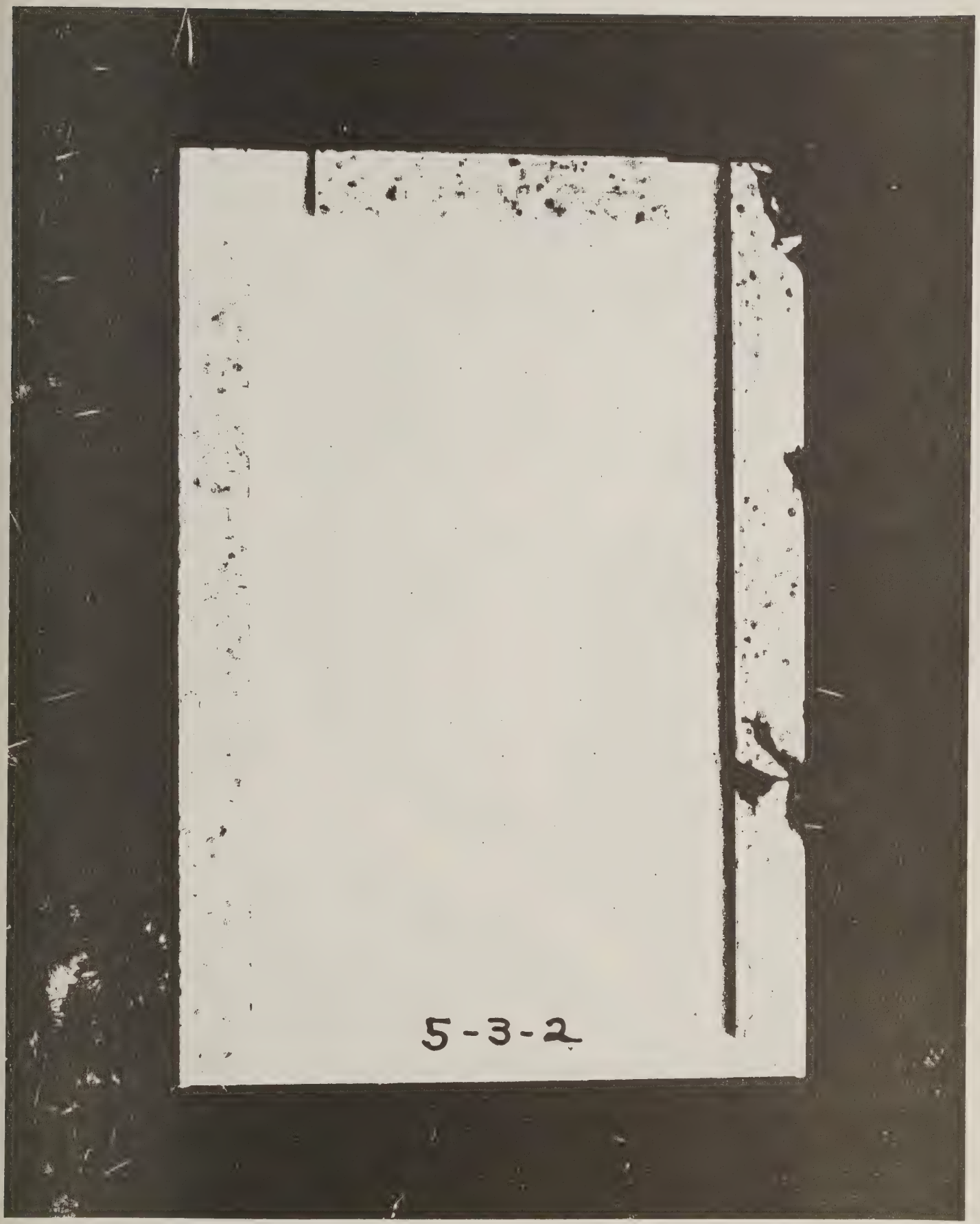


Figure 11.--Standard spray deposit card in cardholder. Card identification is placed on bottom edge for identification. Note spray deposit on card.

41-A

Some type of tote or carrying box (fig. 12) is necessary for the deposit cards. Usually these boxes are fabricated onsite from 1/4-inch plywood. A web strap is attached for carrying the box.

Spray deposit cards are placed in cardholders as shown in figure 11. The holder protects the card, maintains rigidity, simplifies handling, and prevents movement caused by wind.

Cards in holders can be placed on the ground or elevated. In some forest environments such as stands of ponderosa pine, heavily grazed sites have clear forest floors. In these situations, cards can be placed on the ground. Many situations, however, will require that cards be elevated above the ground. This can be accomplished by placing the card on stakes, rods, stumps, logs, or rocks. As a general procedure, the card can be elevated 0.3 to 0.5 meter.

The field foreman should monitor the field crew's performance. He should inventory the cards in the field or at the staging area to insure proper marking, accountability, identity, and to correct poor handling procedures.

Figure 12.--Tote box for carrying deposit cards in holders.

MARKING OF FIELD SAMPLES ON PILOT CONTROL AND OPERATIONAL PROJECTS

John W. Barry

Proper identification of field samples is critical to any field project. Experience has demonstrated that this simple effort frequently is not given sufficient emphasis and, as a result, data for which the project was conducted are lost.

It is the responsibility of the field foreman and laboratory chief to establish a marking system as described here and to instruct the field crew.

A number system was developed along with the automatic data processing program for data analysis of spray deposit cards.

Kromekote® cards should be marked at the bottom with 3/8-inch numbers (figs. 6 and 11). Ballpoint pens are appropriate for marking. Pencils and water soluble inks should not be used.

Samples such as branches, foliage tips, membrane filters, etc., are identified with white marking tape. The number is written on the tape; and the tape is placed on the vial, box, bag, and in some cases, on the branch.

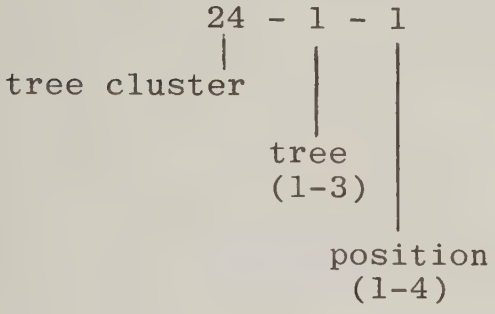
Experience has shown that it is essential that the sample be marked at the time it is picked up in the field. Prior marking or later marking in the laboratory should be discouraged for several reasons related to logistics and timing.

The usual practice is to select between 15 and 25 sample trees per cluster. The clusters should be numbered consecutively, i.e., 1-25 for spray block 1, 26-50 for spray block 2, 51-75 for spray block 3, etc. A letter should not be added to the identification number unless there is a strong reason and the ADP program is adapted to handle the identifier.

Branch samples and the corresponding spray deposit card positioned on the ground beneath the branch should have the same identifier. This allows for comparative analysis between insect mortality and spray deposit.

Sampler marking system is as follows:

Tree card

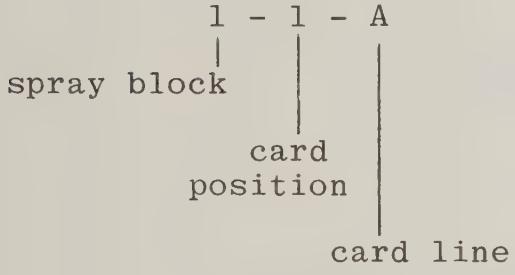


Remarks

Three trees per cluster.

Four card positions per tree.

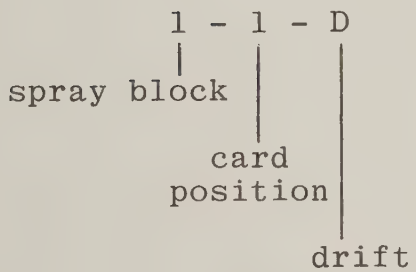
Open card



Number cards in sequence.

Use suffix letters, A, E, I, O, U, for different card lines.

Drift card



Drift cards are distinguished from open cards by a "D" suffix.

SECTION VI

Field Laboratory Assessment Methods

DETERMINING VOLUME MEDIAN DIAMETER

Bohdan Maksymiuk

INTRODUCTION

The degree of pesticide spray atomization affects the effectiveness and safety of insect control. Spray atomizing devices, such as conventional nozzles and spinners, produce a range of drop sizes--the drop size spectrum (Maksymiuk 1964b, 1971a).

In each spectrum, the number of drops decreases with the increased drop size. The ratio of small to big drops is higher in fine sprays than in coarse sprays. Fine sprays can result in a higher index of deposit coverage under favorable meteorological conditions; (for example, number of spray drops per unit area), but the drops are subject to more drift, evaporation, and photodeactivation or weathering of pesticides. In addition, characteristics of the drop size spectrum affect spray behavior, pattern of deposition, and insect mortality (Isler and Thornton 1955, Davis et al. 1956, Maksymiuk 1971b). Therefore, some measure of the drop size spectrum is essential, both for research purposes and for checking and calibrating spray equipment on insect control projects to meet contract specifications and to attain more efficient, safer, and reproducible field practices.

CHARACTERIZATION OF DROP SPECTRA

Various parameters such as volume median diameter (VMD), number median diameter (NMD), mode number or drop size, and average number or drop size, are used for characterizing drop spectra. The VMD, known also as mass median diameter (MMD), is the most commonly used measurement. The VMD is the drop diameter dividing the spray volume into two equal parts--50 percent of the spray volume is in drop sizes below VMD and 50 percent is above VMD. The drop sizes are expressed as drop diameters in micrometers.

Standard methods for determining VMD require accurate sampling of all drop sizes, under ideal meteorological conditions, from the entire spray swath, and the measurement of many drops of all sizes (Maksymiuk 1964b). The image analyzer (Quantimet®), used for automated drop sizing, does not eliminate the above problems. In addition, these methods are complicated, requiring special equipment and trained personnel, and cannot be used in the field for rapid determination of VMD.

VOLUME MEDIAN DIAMETER

This paper describes a simple and rapid method for determining VMD from the largest drop (D-max) in the continuous spectrum. Only the size of the five largest drops for each single-swath test flight is needed. Spray tests can be conducted under a wide range of meteorological conditions because there is no need to sample small drops.

Maksymiuk (1964a) described the development of the D-max method for determining VMD. Moore et al. (1964) reported on the precision and accuracy of this method. Isler and Carlton (1965) summarized use of the D-max method for research purposes in determining VMD of sprays under a wide range of test conditions. The D-max method also proved highly satisfactory for use on spray projects (Maksymiuk 1963a).

The D-max method saves more than 90 percent in time without loss of accuracy or precision compared with the method requiring sampling and measurement of all drop sizes. It has been successfully tested over a wide range of spray atomizations, mainly with oil-base spray formulations and, to a lesser degree, with water-base formulations (Isler and Maksymiuk 1961; also, unpublished data on file at Forestry Sciences Laboratory, Corvallis, Oreg.).

PROCEDURE

Step-by-step procedures for determining VMD of spray deposits by the D-max method are as follows:

A. Spray equipment

1. Make sure all spray nozzles and nozzle tips are the same, are oriented in the same direction, and are in good working condition--old tips can become eroded.

2. Adjust the spray application volume so that it does not exceed 1 gallon per acre. Higher application rates might result in drops overlapping on the assessment cards, making determination of drop size difficult. The application rate can be reduced with fewer nozzles, but the spray pressure must not be changed because it affects the drop size. When reducing the application rate is not practical, fly the spray plane higher and crosswind so that small drops are blown away from the center of the flight line.

B. Drop sampling

For drop size sampling it is preferable to use Kromekote® cards.

1. Oil-base sprays--you can sample undyed spray on dyed oil-sensitive cards (White 1959) or dyed spray on undyed cards (Maksymiuk and Moore 1962).
Water-base sprays--you can sample dyed spray on undyed cards. Use oil-soluble dyes for oil formulations and water-soluble dyes for water formulations (2 lb oil-soluble or water-soluble Sudan Black dye (made by General Dyestuff Corp.) per 50 gallons of spray or other dyes).

2. Set a line of about 40 cards on a runway or in an open area, preferably alined to wind direction (see fig. 13). Use wire cardholders (Maksymiuk 1959) to support the cards above ground vegetation. Place cards as follows:

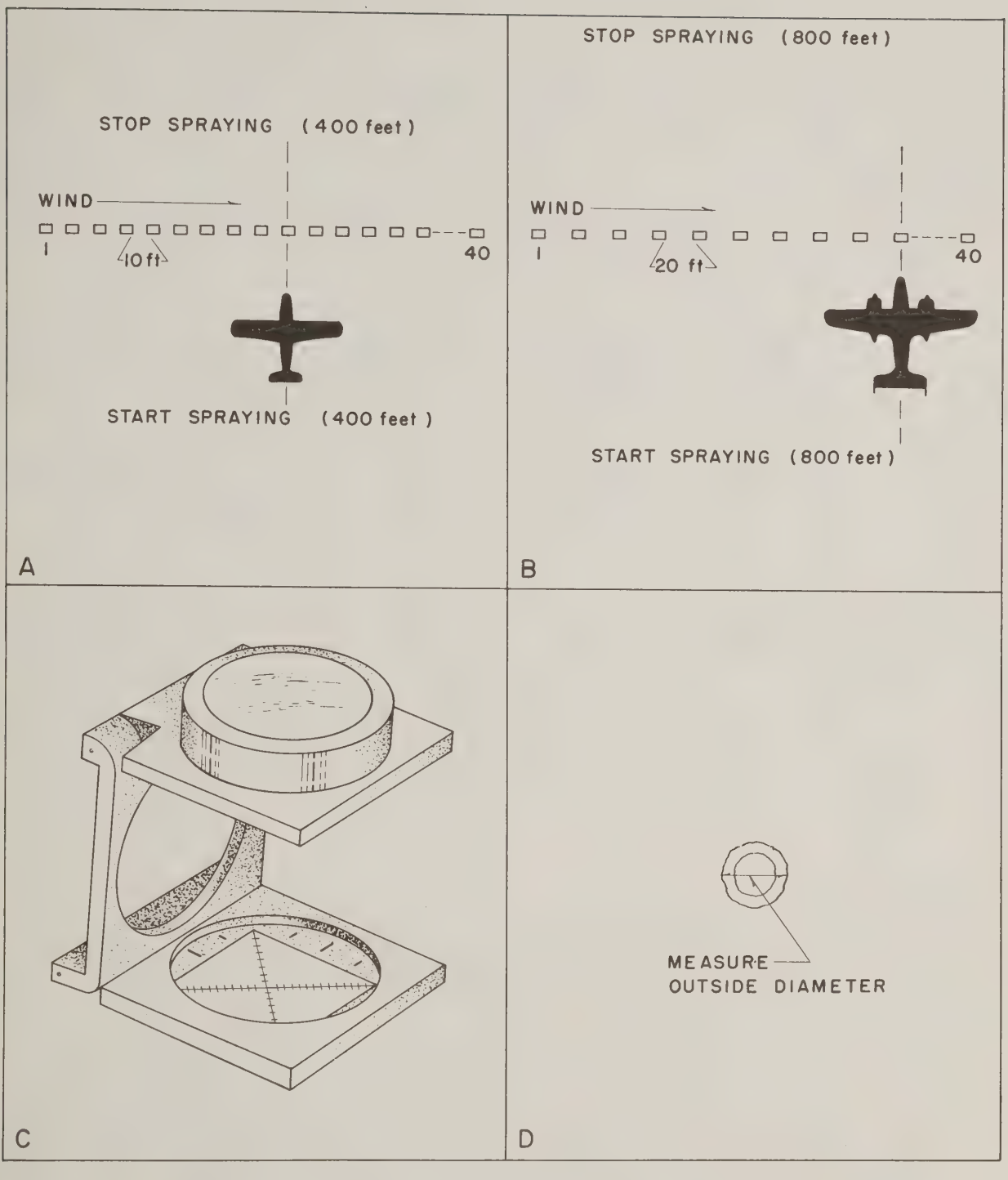


Figure 13.--A, Arrangement of sample cards for small aircraft; B, arrangement of sample cards for large aircraft; C, linen tester equipped with eyepiece reticle for measuring spot diameters; D, halo surrounding spots on dyed cards.

a. At 10-foot intervals for *slow-speed aircraft* (about 80 to 100 m/h) like the Stearman, Piper, and helicopters.

b. At 20-foot intervals for *medium-speed aircraft* about 150 to 180 m/h) like the TBM, DC-3, B-18, B-17, and helicopters.

C. Flight procedures

1. Spray over the cards at a right angle to the sampling line (fig. 13).

   a. Slow-speed aircraft. Spray from a height of 50 feet or more; turn on the spray about 400 feet before the sampling line and turn it off about 400 feet beyond the sampling line.

   b. Medium-speed aircraft. Spray from a height of 100 feet or more; turn on the spray about 800 feet before the sampling line; and turn it off about 800 feet beyond the sampling line.

2. Meteorological conditions are not critical, provided wind-speed is less than about 8 m/h and there is no rain. At higher windspeeds, the drops often produce oval or streaked spots of meaningless dimensions. When crosswind flights are made, the largest drops, from which D-max is selected, will fall under the airplane or will be shifted slightly downwind. The smaller drops will be carried downwind and will not overlap or be superimposed on the larger drops. Therefore, a crosswind of from 1 to 6 m/h is desirable.

D. Determining drop D-max

1. Allow at least 10 minutes for the drops to spread and dry on the cards before measuring the spots; allow more time for very large drops or for spray formulations that evaporate slowly.

2. After the spots stop spreading, select and measure the diameters of the five largest spots, including the halo if dyed cards are used (fig. 13). Measure the spots to the nearest 100 micrometers (0.1 mm). The spots can be measured with a microscope eyepiece reticle, graduated in 100-micrometer units. This reticle can be used either in a microscope or it can be attached with Scotch tape to the bottom of a linen tester or other magnifier. A linen tester gives a direct measurement because it magnifies both the spot and the scale at the same rate. Reticles and linen testers can be bought at any scientific supply house (for example: Edmund Scientific Co., Barrington, N. J.; crossline reticle, scales 10 mm in 100 parts; linen tester magnifier, 6X lens diameter 1 inch). Tabulate the spot diameters in order of decreasing size as shown in the example under step 4 below.

3. Convert the spot diameters to spherical drop diameters by dividing the spot diameters by the proper spread factors. The spread factor shows how much the drops spread on the cards. It varies with drop size and the components of the spray formulation. It is determined in advance for the drop sizes, spray, and sampling surface to be used. It is obtained by dividing the diameter of spherical drops of known size into the outside diameters of the spots they produce on the cards. A method for determining spread factor is described by Maksymiuk and Moore (1962). Spread factors for various spray formulations are given by Maksymiuk and Moore (1962), Maksymiuk (1963a), and Waite (1977). Determination of spread factor requires specialized skill and equipment. The above sources can be used for the spread factors of the same formulations or possibly similar ones. It is recommended that the spread factor be determined for each formulation. For example, an error of 3 percent in determining drop size will result in 9 percent error in volume; therefore, spread factor should be determined accurately.

4. Select spherical drop D-max as the largest drop diameter with not more than 32 micrometers difference between it and the next largest spot to it--going from the smallest drop size up. In the following example, drop D-max is 390 micrometers:

Spot on card		Spread factor	Spherical drop diameter	VMD, for aircraft of	
				Slow speed	Medium speed
No.	Diameter				
	Micrometers		- - - - -	Micrometers	- - - - - -
1	4,000	6.28	637	--	--
2	3,800	6.27	606	--	--
3	2,400	6.15	390	177	156
4	2,300	6.14	375	--	--
5	2,300	6.14	375	--	--

Drops larger than D-max are only found occasionally. They are sometimes caused by leaks or by drooling of impinged spray from the equipment or from the surfaces of the aircraft. If they are present, check your spray equipment.

E. Converting drop D-max to VMD

1. Obtain MMD as follows:

   a. Slow-speed aircraft. Divide spherical drop D-max by 2.2, or multiply it by 0.454.

   b. Medium-speed aircraft. Divide spherical drop D-max by 2.5, or multiply it by 0.400.

2. Since there is variation in VMD from flight to flight (Moore et al. 1964), use the average of not less than three test flights.

It is recommended that convenient tables, similar to table 3, be prepared by users.

Table 3--*Estimated VMD for slow- and medium-speed aircraft using spread factors for an oil spray*[1/] *on dyed Kromekote® cards*

Spot diameter	Spread factor	Spherical drop diameter	VMD, for aircraft of	
			Slow speed	Medium speed
Micrometers		Micrometers		
1 000	5.74	174	79	70
1 100	5.80	190	86	76
1 200	5.85	205	93	82
1 300	5.90	220	100	88
1 400	5.94	236	107	94
1 500	5.97	251	114	100
1 600	6.00	267	121	107
1 700	6.03	282	128	113
1 800	6.05	298	135	119
1 900	6.07	313	142	125
2 000	6.09	328	149	131
2 100	6.11	344	156	138
2 200	6.12	359	163	144
2 300	6.14	375	170	150
2 400	6.15	390	177	156
2 500	6.16	406	185	162
2 600	6.18	421	191	168
2 700	6.19	436	198	174
2 800	6.20	452	205	181
2 900	6.21	467	212	187
3 000	6.21	483	220	193
3 100	6.22	498	226	199
3 200	6.23	514	234	206
3 300	6.24	529	240	212
3 400	6.24	545	248	218
3 500	6.25	560	255	224
3 600	6.26	575	261	230
3 700	6.26	591	269	236
3 800	6.27	606	275	242
3 900	6.27	622	283	249
4 000	6.28	637	290	255
4 500	6.30	714	325	287
5 000	6.31	792	360	317
5 500	6.33	869	395	348
6 000	6.34	946	430	378
6 500	6.35	1 023	465	409
7 000	6.36	1 100	500	440

[1/] Spray formulation: 1 lb DDT plus 1 quart of Sovacide (Mobisol 544-B) plus No. 2 fuel oil to make 1 gallon of spray.

DETERMINING DROPS PER SQUARE CENTIMETER

Lynne Whyte

Determination of droplet density (drops per square centimeter) on Kromekote® cards in the field laboratory requires hand counting. This can be accomplished by acquiring the equipment listed below and following the described procedures.

1. Equipment for field laboratory analysis

In developing the list of equipment required for the field laboratory analysis of spray characteristics, it has been assumed that 110-volt power, desks, and chairs are available to the laboratory crew. Any indoor site is adequate for field analysis.

Equipment	Use
Cork bulletin board	Work base for sizing and counting drops
Push pins	Tacking card to bulletin board
High-intensity lamp	High-intensity illumination of counting area
Templates	Identification of card area for counting and sizing drops
Pencils, pencil sharpeners, grease pencils, cleaning tissue, stapler, note pads, envelopes, rubber bands, paper clips	Data recording, data organization
Measuring magnifier	Counting and sizing drops

The cork bulletin board should be large and sturdy since it will serve as a work base for sizing and counting the drop stains. The cork bulletin board No. 30-AF-18 x 24 manufactured by Wesco Products, Gardena, California, is of ideal size and construction. Bulletin board push pins with large plastic heads provide firm tacking of the sampler cards and templates to the cork bulletin board work base. A high intensity, gooseneck desk lamp, such as the Student Model 7200 manufactured by Tensor Corporation, Brooklyn, New York, is ideal for illuminating the working surface at the low-angle required for counting and sizing the stains. The measuring magnifier should have 100-micrometer (0.1 mm) divisions for estimating stain sizes. Bausch and Lomb, Rochester, New York, manufactures a small measuring magnifier (Catalog No. 81-34-35) with a clear plastic body which is ideally suited for this purpose.

The procedures described here require the use of clear plastic templates to overlay the exposed sample cards. Since continued use

of the templates will eventually result in their becoming scratched and unusable, replacements will be necessary; a draftsman can draw the templates, using No. 0000 Leroy pen, on tracing paper at three times the size shown in figure 14. This original drawing is then photographed and reduced 33.3 percent and reproduced on clear 4-mil Mylar film. The negative produced in this process can be used over and over to make new templates.

2. Method

A template (fig. 14) and measuring magnifier are used to count drops in the field laboratory. The 4-, 8-, and 16-square centimeter areas are arranged on the template so that the top of the area to be counted is at the center of the card when the line at the top of the template labeled with the corresponding area is alined with the top of the sampling card. Drops within a 4-, 8-, or 16-square centimeter area are counted. Select an area which will include at least 200 drops. With a little experience, one can readily select the proper area to be counted by visual inspection of the card. After selection, the area should be examined for obvious anomalies that might affect accuracy. These anomalies include smeared drops, foreign matter on the card or shadows (absence of drops) where deposition has been prevented by a leaf or some other object. If anomalies occur, move the template to an unaffected portion of the card. Once an anomaly-free area has been found, anchor the template and card to the corkboard with push pins. The results of the drop density count are recorded on the Drop Density Data Sheet. Record the trial number, row per line number, card number, and area being counted.

Small stains should not be counted because they do not contribute significantly to mass recovery (i.e., ounces per acre recovered vs. ounces per acre applied) and because experience has shown their inclusion makes uniformity in counting difficult. When the measuring magnifier is used, stains of less than 50 micrometers (μm) in diameter should not be counted. If drops with stains of less than 50 μm are important in determining mass recovery (more than 5 percent of the mass distribution is comprised of drops with stains of less than 50 μm in diameter), a more precise instrument is required to count and measure the stains. As a general rule, drops with diameters of three less than the volume median diameter (VMD) estimated in the field do not greatly contribute to mass recovery.

The template areas in figure 14 are divided into five columns to assist in counting the drops. Each column is counted using the measuring magnifier. The total number of drops for each column is noted on scratch paper. Stains that intersect the outer perimeter of the template area should be included in the count only if more than one-half their area is inside the perimeter line. Stains that intersect the lines dividing the area into columns must be counted only in one column, usually by assigning them to the column at the left of the line no matter how much of the stain is contained in a column. After the five columns are counted, the results are summed and entered in the "Stain count" column of the Drop Density Data Sheet. The drop density is calculated by dividing the stain count by the template area used. The result is entered in the "Drop density" column on the Data Sheet. All cards included in the swath width are counted.

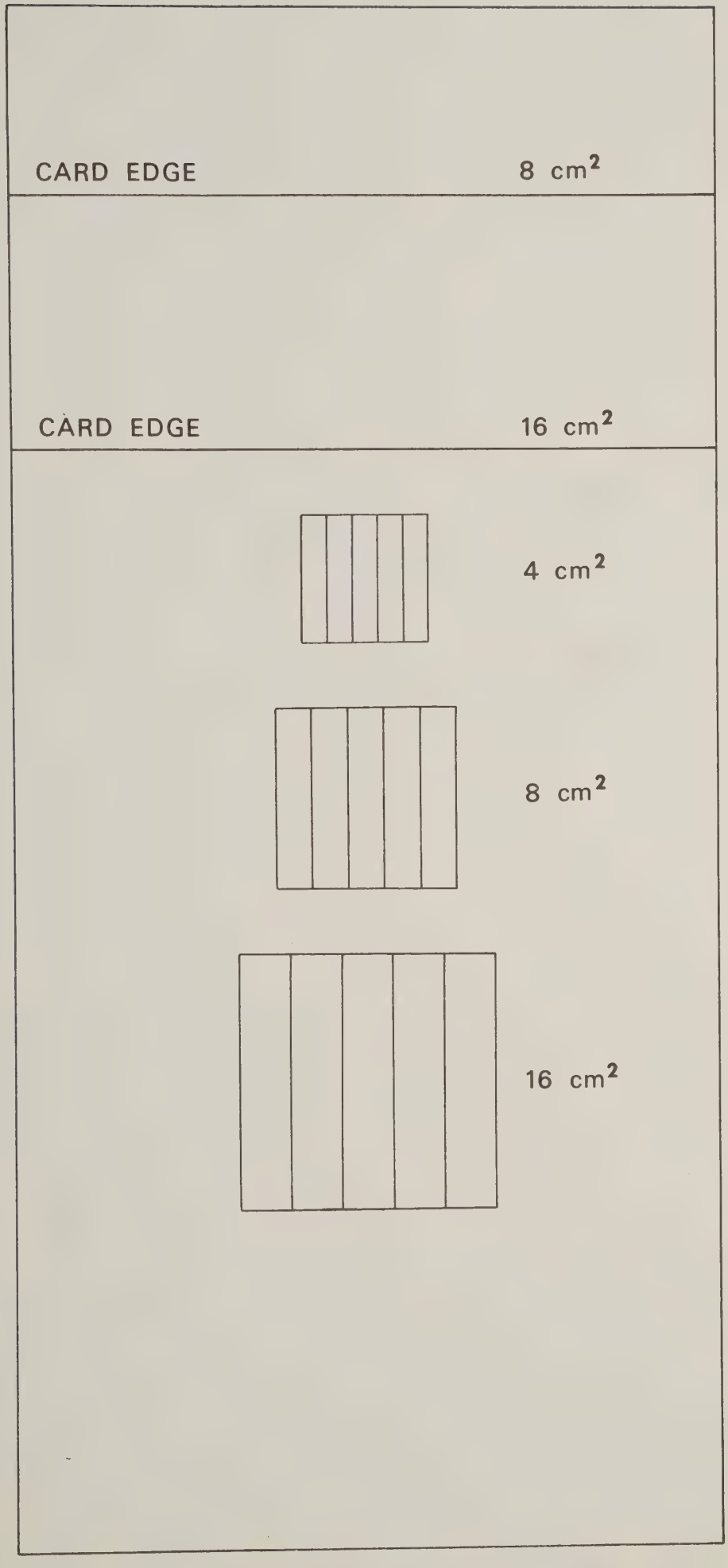


Figure 14.--Template for counting and sizing drops on sampler cards.

Drop Density Data Sheet

Card number	Template area (cm^2)	Stain count	Drop density (drops/cm^2)

SECTION VII

Laboratory Analysis Methods

SPREAD FACTORS

Richard Waite

INTRODUCTION

Two of the most important physical factors affecting the outcome of a spray program are dosage and degree of spray coverage on the target area. Dosage is determined mainly by the concentration of active ingredient and the amount of deposit. Degree of spray coverage on the target area is principally a result of atomization, application rate, and meteorological conditions. These variables must be monitored to obtain knowledge of the effect of insecticides.

Aerodynamic drops, on impact, will spread on Kromekote® cards and on most other collecting surfaces. Spreading and the degree of spreading depend on the physical properties of the collecting surface and the spray formulation.

Because drop diameters are required for determination of atomization and quantity of spray, the stain marks on the Kromekote® cards are converted to actual drop size by means of a corrective spread factor. This conversion factor is the ratio of the diameter of the stain to the diameter of the aerodynamic drop causing it. The determination of a particular spread factor involves the production, collection, and measurement of groups of uniform-size droplets from which a calibration curve can be made.

In this paper, we are concerned only with the method used to determine the drop size of spray received on a flat, smooth, sampling surface.

DROPLET GENERATION

A number of different methods for producing droplets of uniform size have been tested: rotary devices (McKinlay and Glen 1971, Rayner and Haliburton 1955), vibrating capillary tubes (Schneider and Hendricks 1964, Mason et al. 1963), and perhaps the most common, the vibrating reed apparatus (David 1951, Rayner and Hurtig 1954, Wolf 1961).

DROPLET COLLECTION

The earliest methods of assessing droplet size used coated glass slides or plates. The slides were smoked or coated with some material such as magnesium oxide (May 1950). Impinging droplets produced craters which could be correlated directly with droplet diameter. A refinement of this technique is the use of collection fluids which are immiscible with the sampled droplets. Viscous polybutene (Fisher and Dougan 1970), thixotropic solutions (Daum et al. 1968), mineral oil-vaseline, and water-soap solution mixtures (Hurtig and Perry 1950) are some collection fluids. The suspended droplets are measured microscopically or photographically.

For an understanding of the effects of aerial application of certain pesticides, relationships must be determined between insect mortality and spray factors such as drop density, atomization, and gallons per acre. Spray deposit assessment is the key to the determination of these factors. The cards placed in the spray area are analyzed in the laboratory using an image analyzer to give these values. Because atomization and gallons per acre require actual drop diameters, a corrective spread factor must be used.

DROPLET GENERATOR

Our method of producing uniform spherical droplets is by means of a vibrating reed apparatus (fig. 15) similar to that described by Davis (1951). The reed, with a needle affixed to the end, is tuned to resonance to produce maximum amplitude. Streams of droplets are formed as the needle passes through the liquid emanating from a hypodermic syringe. A monometer assures a constant flow of liquid to the needle, thus replacing the material lost to the streams of droplets. Back lighting allows easy viewing of the streams of droplets. A range of droplet diameters from approximately 50 to 500 micrometers can be obtained from this apparatus by varying the frequency of the reed vibration, the needle size, the flow rate, and the position of the reed in the flow of liquid from the syringe.

DYES

For a visible stain on our sampling cards, a dye is added to the spray formulation. We have used mainly fluorescent dyes such as Brilliant Sulpho Flavin (BSF) and Rhodamine B extra S, which are water soluble, and Rhodamine B extra base, an oil-soluble dye. Some nonfluorescent dyes are Nigrosine (black), a water soluble dye, and Sudan Deep Black, and oil-soluble dye.

For the most part we have found that a concentration of 0.1 percent weight per volume is compatible with our work. For automatic card reading, however, a higher concentration is desirable with some formulations, as the image analyzer needs a good contrast to distinguish spots accurately.

Spread factor determination in our laboratory is accomplished by passing cards and magnesium oxide (MgO) coated slides through a stream of uniform-size droplets. According to May (1945), the spherical drop diameter is the crater diameter formed as the droplets contact the MgO coated slide, multiplied by a conversion factor of 0.86. The thickness of the MgO coating must be at least the diameter of the impinging drops. The slides are viewed with a binocular microscope with a reticle containing a calibrated scale inserted in one of the oculars. Under transmitted light, the inside diameters of the craters are readily visible and easily measured (in our case to the nearest 50 micrometers). Spots on the cards are viewed with reflected white or UV light depending on the dye used. The outside diameter of the spots are also measured to the nearest 50 micrometers. Sufficient time must be allowed for the spots to cease spreading before they are measured. The time needed will depend on the type of formulation. Water-base formulations have reached

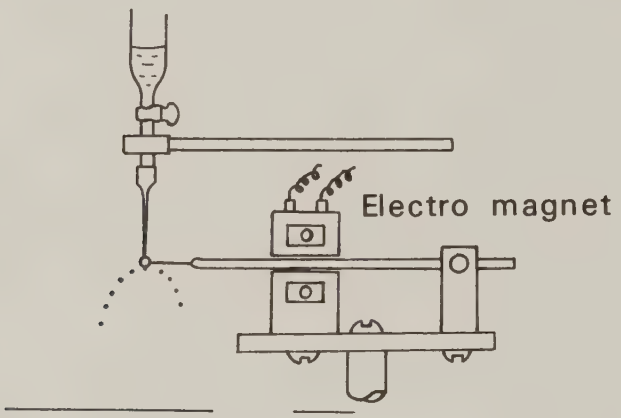


Figure 15.--Vibrating reed apparatus for generating droplets.

maximum spread in less than 1 hour, whereas oil-base formulations should set overnight for maximum spread.

Variation is minimized using the mean of 10 spots or drops from each card or slide. These values are used in the following formula for the spread factor determination of drop size:

$$\text{Spread factor} = \frac{\text{Outside spot diameter}}{\text{Inside MgO crater diameter X } 0.86}$$

To account for the variation of spread factor with drop size, the spread factor must be determined for the working range of drop sizes. Maksymiuk and Moore (1962) found that the relationship between drop diameter and spot diameter for fuel oil No. 2 was linear for drops larger than 125 micrometers. The linear regression equation can, therefore, be conveniently used when spot diameters must be converted to drop diameters.

Several complicating factors have become evident in spread factor determination. Halo effects around spots is one problem we encountered with some formulations. In some cases this is due to the greater spreading of a certain phase of the formulation. Halos can also be formed if the sampling card is damp from dew or rain. When caused by the formulation, halos should be included as part of the droplet size. In such a case the spreading of the spot is due to the formulation and becomes an integral part of the spread factor. Precautions should be taken to prevent cards from becoming damp. Trying to match those exact conditions of dampness for a spread factor calibration is difficult to achieve in the laboratory.

Another, related problem is that of uneven spread of certain formulations or drop skewing caused by wind. That is, the drop forms an irregular shaped spot, not a circular spot. Circular spots are measured by taking an average of the maximum and minimum dimensions.

There are several problems related to the type of droplet generator used. Water-base formulations differ from the oil base because they do not generally form the two streams of uniform-size droplets as the vibrating reed removes liquid from the syringe. It is often very difficult to isolate streams of droplets of uniform size.

Many formulations contain particulate material which settles and often plugs the syringe needle. A magnetic stirrer in the syringe will frequently solve this problem. Filtering to remove these particles has been used occasionally; however, the spread factor in this case does not represent the complete formulation.

Due to the time-consuming process of preparing MgO-coated slides, collection fluids such as mineral oil, Indopol H-1900® (Amoco), Dow Corning 200® dielectric fluid, and thixotropic solutions of water and Natrosol 250 HR® were examined as quick alternate methods. These methods are very appealing and show great promise. Mineral oil is a good collection fluid for Dipel® and Thuricide® formulations. The drops, however, must be measured immediately as they quickly settle to the bottom and spread. The other solutions were briefly tested with varying degrees of success. Indopol, being extremely viscous, does not settle, but due to its viscosity, it is more difficult to use. The

Dow Corning fluid also has a settling problem, but the rate of settling is much slower than that of mineral oil. Suspended droplets of certain formulations decrease in size over a short time period. This indicates that the formulations were not completely immiscible in the Dow Corning dielectric fluid.

IMAGE ANALYZER FOR CARD ASSESSMENT

Richard Waite

An image analyzer, such as the Quantimet® 720, has become a necessity in spray deposit assessment due to the increasing volume of analyses and the need for more consistent results. The microscope method of card analysis works well for a limited number of cards; however, as the number of cards increases, the efficiency of the technician and accuracy of the results decrease. The time required to process cards by the microscope method averages 20 minutes per card; analysis of the same card by the image analyzer takes 1 minute.

Kromekote® cards have been used for a number of years as sampling surfaces for spray deposit assessment. Fortunately, they are an excellent surface to view with the Quantimet® because of their short fiber construction and uniform background. Well-defined spots form on Kromekote® cards, making accurate detection possible. The high quality sampling surface has simplified the transition from the microscope method of card analysis to that of image analysis with the Quantimet®

The image analyzer used in spray deposit assessment is usually set up to count spots in predetermined class sizes either by diameter or area. The Quantimet® is essentially a closed-circuit television system which views the cards placed in a special, uniformly illuminated holder. After it is focused properly, the instrument is adjusted to the correct threshold or gray level. Correction makes possible the use of the analyzer to detect the true size of the spots. The analyzer may be operated in manual mode showing the number of counts for each size class on a video output display; or, the operator may select the more usual automatic mode which passes the information directly to a computer or calculator within a few milliseconds. The necessary computations are processed and final answers given immediately.

Spray deposit assessment gives information about atomization (droplet spectrum), drop density, and volume of spray per unit area. The degree of atomization is expressed either as volume median diameter (VMD) or number median diameter (NMD). Degree of atomization is defined as the drop diameter where 50 percent of a spray volume (or the number of drops) are of diameters greater than the VMD (or NMD) and 50 percent are of diameters less than the VMD (or NMD). Drop density is the number of spots per square centimeter. Volume of spray is usually expressed in gallons or ounces per acre. At times, the cumulative percent volume or cumulative percent number for selected class sizes is also used.

The image analyzer has certain inherent problems. The analyzer may detect dirt or other marks on the card along with the spray deposit. Overlapping spots are not distinguished as separate entities except by a special time-consuming process. Small features or features with low contrast may not be detected by the Quantimet® due to limit of resolution, shading problems, or sensitivity of the threshold. The Quantimet® detects features in distinct quantities called picture points; therefore,

if a feature is smaller than one picture point, it will not be detected. The limit of resolution depends on the lens system used. For example, a 63-mm lens has a resolution of 45 micrometers; whereas, the use of a 75-mm extension tube with this lens gives a resolution of 12 micrometers.

When the resolution (magnification) is increased by a change in lens, the view of the sampling area decreases. In the example above, the area of the field of view decreases from 8.98 cm^2 to 0.66 cm^2. Shading due to nonuniform illumination of the sampling surface causes problems such as partial detection of features and detection of electronic noise. Since proper threshold allows selected gray levels to be detected, the instrument is more likely to detect fiber and dust as the shade difference between spots and the background decreases.

The main problem encountered in card analysis is the poor condition of the cards. Cards that are wrinkled or curled will have spots in different focal planes, resulting in erroneous results at varying magnifications. Dirt particles, fingerprints, and smears may be detected along with the spray deposit, and cards moistened by rain or dew may have halos around the spots. Special precautions must be exercised to preserve the cards from these abuses in the field. The cards should be treated as photographs.

An image analyzer laboratory is set up for rapid analysis of many cards. It is imperative that each card be clearly and distinctly identified to prevent confusion and errors in recordkeeping. The identification marks should be within one-half inch of an edge on the front of a card.

SPECTRAL COUNTS OF CARDS FOR MASS DETERMINATION

Lynne Whyte

Spectral counts in the field laboratory are useful because the mass median, mass mean, and number median diameters can be rapidly determined from the drop-size distribution for the swath (Dumbauld and Rafferty 1976). The total mass of deposited spots can also be determined by use of data from the spectral counts. The drop spectrum analysis of five cards within the swath width is normally sufficient to estimate these parameters within 15 percent of the values that would have been obtained if all cards within the swath had been analyzed. The error is frequently less than 5 percent. One card from each end of the swath, one card near the center of the swath, and one card on each side of the center card located approximately half the distance between the end and center cards make up the five cards.

Before the drops are counted and sized, the drop-size categories must be specified.

SELECTION OF SIZE CLASS INTERVALS

Normally, 8 to 10 drop-size intervals are sufficient to define the drop spectrum. The upper and lower limits of the stain size intervals must be determined before the stains are counted and sized. The following procedure for selecting the limits of the intervals is suggested:

1. Draw the line defining the relationship between stain and drop diameter on linear graph paper as shown in figure 16, using the equation $DD = a + b\,(SD) + c\,(SD)^2$;

   where, DD = drop diameter
   and
   SD = stain diameter.

   The values a, b, and c are constants which are determined in the laboratory for each spray formulation. This line will show a relationship between the aerodynamic drop size and the stain diameter.

   In figure 16, a=7.68, b=0.199, $c=5.73 \times 10^{-6}$. The line should extend from the smallest diameter stain to the largest diameter stain.

2. Mark the position on the line of the stain VMD estimated by the D-max method. For example, the point marked + in figure 16 corresponds to a VMD stain diameter of 600 μm or a drop diameter of 130 μm.

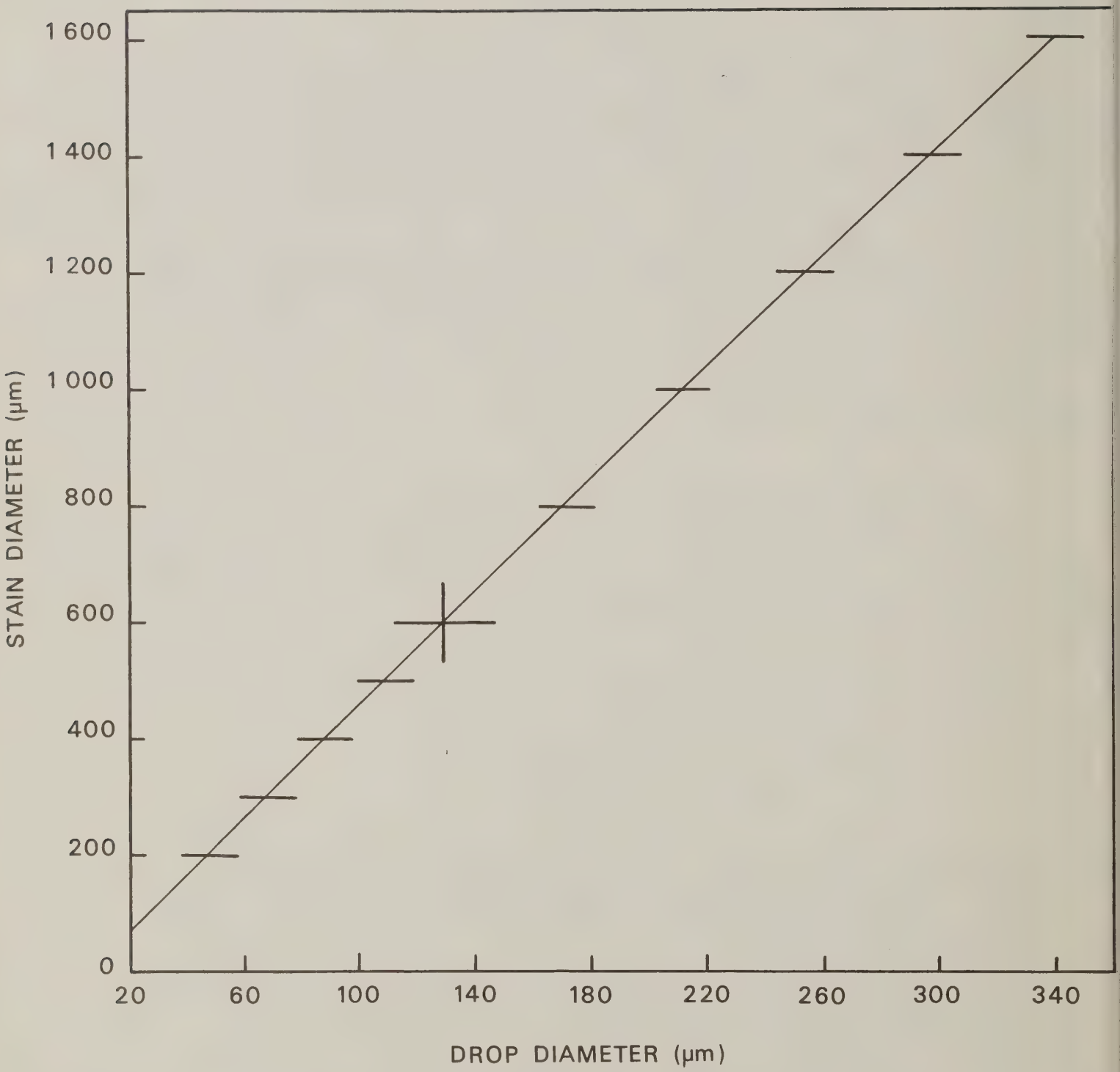


Figure 16.--Stain factor relationship for example trial data. The + symbol is the stain VMD obtained from the estimated D-max field analysis (drop diameter = a+b(stain diameter)+c(stain diameter)^2; a = 7.68, b = 0.199, c = 5.73x10^{-6}).

3. Divide the line in figure 16 into about five intervals below the point marked + using standard intervals of 50 μm, 100 μm, or multiples of 50 μm stain intervals. The measuring magnifier is not accurate if the intervals are less than 50 μm. For the example shown in figure 16, the upper limits of the stain intervals become 200, 300, 400, 500, and 600 μm as shown by the short horizontal lines. The lower limit of the smallest interval should correspond to the smallest drop in the spray deposit density count.

4. Divide the line in figure 16 above the point marked + into five intervals using standard intervals of 50 μm, or 100 μm, or other multiples of 50 μm. In the example shown in figure 16, this procedure results in stain category upper limits of 800, 1 000, 1 200, 1 400, and 1 600 μm. If the VMD estimated by the D-max method is less than 100 micrometers, it may be necessary to divide the straight line above the point marked + into more than five intervals to obtain a representative mass distribution.

It should be noted that the basic graph shown in figure 16 can be generated before the trials. Enter the stain class intervals on the drop spectrum data sheet (fig. 17) and use the stain factor equation to convert the stain upper limits to drop-size upper limits. Enter the drop-size upper limits on the drop stectrum data sheet.

After the drop size categories are determined, the drops on the cards can be counted and sized. The template used in figure 14 (for hand counting Kromekote® cards in the field) is also used in making the spectral counts. A minimum of 200 stains should be counted and measured to obtain drop densities. The measuring magnifier is used to size stains and classify them according to stain size categories.

After the card and template have been secured to the corkboard with push pins, the magnifier is used to measure the drops in each column (fig. 18). Counting and sizing is best accomplished by two people, one to size the drops and another to record each drop in terms of a size-category number. After the stains in each column are counted and sized, the number of stains in each category is totaled. When the counting and sizing of drops in all five columns of the selected area have been completed, the subtotals are added and the total number of stains in each size category entered on the form (fig. 17) for each card analyzed.

After all five cards have been analyzed, determination of the drop-size distribution parameters can proceed. For convenience in explaining the calculations, the rows used in these calculations on the drop spectrum data sheet (fig. 17) have been identified by the letters A through I.

Row A, mean drop diameter

The volume mean drop diameter in each size category is calculated from the expression

$$\bar{d} = \left(\frac{d_2^3 + d_1^2 d_2 + d_1 d_2^2 + d_1^3}{4} \right)^{1/3};$$

Figure 17.--Drop spectrum data.

Test 9 Row/Line C Spray material DYLOX Material density 1.067 (g cm^{-3})

Analyst: John Doe Stain factors: a = 7.68, b = 0.199, c = 5.73x10^{-6}

		Size category												
		1	2	3	4	5	6	7	8	9	10	11	12	Total
Stain upper limit (μm)		100	200	300	400	500	600	800	1000	1200	1400	1600		
Stain lower limit (μm)		50	100	200	300	400	500	600	800	1000	1200	1400		
Drop upper limit (μm)		27.6	47.7	67.9	88.2	109	129	171	212	255	298	341		
Drop lower limit (μm)		17.6	27.6	47.7	67.9	88.2	109	129	171	212	255	298		
CARD NO. 43 TEMPLATE AREA 16 cm^2	NUMBER OF DROPS	41	118	121	85	85	40	45	7	2	1	0		545
	DROP DENSITY (drops cm^{-2})	2.562	7.375	7.562	5.312	5.312	2.500	2.812	0.4375	0.1250	0.0625	0		34.06
CARD NO. 46 TEMPLATE AREA 8 cm^2	NUMBER OF DROPS	44	83	54	21	21	11	5	3	1	0	0		243
	DROP DENSITY (drops cm^{-2})	5.500	10.380	6.750	2.625	2.625	1.375	0.6250	0.3750	0.1250	0	0		30.38
CARD NO. 50 TEMPLATE AREA 8 cm^2	NUMBER OF DROPS	69	91	60	24	14	5	2	1	0	0	1		267
	DROP DENSITY (drops cm^{-2})	8.625	11.38	7.500	3.000	1.750	0.6250	0.2500	0.1250	0	0	0.1250		33.38
CARD NO. 54 TEMPLATE AREA 8 cm^2	NUMBER OF DROPS	44	105	84	35	25	19	5	1	0	0	0		318
	DROP DENSITY (drops cm^{-2})	5.500	13.12	10.50	4.375	3.125	2.375	0.6250	0.1250	0	0	0		39.74
CARD NO. 57 TEMPLATE AREA 8 cm^2	NUMBER OF DROPS	8	21	36	26	43	39	20	9	3	0	0		205
	DROP DENSITY (drops cm^{-2})	1.000	2.625	4.500	3.250	5.375	4.875	2.500	1.125	0.375	0	0		25.625
CARD NO. TEMPLATE AREA cm^2	NUMBER OF DROPS													
	DROP DENSITY (drops cm^{-2}													
A	Mean drop diameter (μm)	23.0	38.5	58.4	78.5	99.0	119.3	151.0	192.2	234.2	277.1	320.0		
B	Mean drop mass (mg)	6.796 x10^{-6}	3.188 x10^{-5}	1.113 x10^{-4}	2.703 x10^{-4}	5.421 x10^{-4}	9.486 x10^{-4}	1.924 x10^{-3}	3.967 x10^{-3}	7.117 x10^{-3}	1.189 x10^{-2}	1.831 x10^{-2}		
C	Sum of drop densities by size category	23.19	44.88	36.81	18.56	18.19	11.75	6.812	2.188	0.625	0.0625	0.125		
D	Average drop densities by size category (drops cm^{-2})	4.638	8.976	7.362	3.712	3.637	2.350	1.362	0.4375	0.1250	0.00125	0.025		
E	Cumulative drop densities	4.638	13.61	20.98	24.69	28.33	30.68	32.04	32.48	32.60	32.61	32.64		32.64
F	Cumulative percent of drop densities	14.21	41.70	64.28	75.65	86.80	94.00	98.17	99.52	99.88	99.91	100		
G	Average deposition by size category (mg cm^{-2})	3.152 x10^{-5}	2.862 x10^{-4}	8.194 x10^{-4}	1.003 x10^{-3}	1.972 x10^{-3}	2.229 x10^{-3}	2.620 x10^{-3}	1.736 x10^{-3}	8.971 x10^{-4}	1.486 x10^{-5}	4.518 x10^{-4}		
H	Cumulative mass (mg)	3.152 x10^{-5}	3.177 x10^{-4}	1.137 x10^{-3}	2.140 x10^{-3}	4.112 x10^{-3}	6.341 x10^{-3}	8.961 x10^{-3}	1.070 x10^{-2}	1.159 x10^{-2}	1.161 x10^{-2}	1.207 x10^{-2}		1.207 x10^{-2}
I	Cumulative percent of mass	0.26	2.63	9.42	17.73	34.04	52.55	74.26	88.67	96.05	96.21	100		

Figure 18.--Counting and sizing stains on cards with pocket magnifier.

where,

d_1 = drop lower limit for the size category
and
d_2 = drop upper limit for the size category.

For example, the entry in the first column of row A is calculated as

$$\bar{d} = \left[\frac{(27.6)^3 + (17.6)^2 27.6 + 17.6(27.6)^2 + (17.6)^3}{4}\right]^{1/3}$$

$$= 23.0 \ \mu m$$

Repeat the calculation for each size category and enter the result in the appropriate column of row A.

Row B, mean drop mass

The mean drop mass in milligrams for each size category is calculated from the relationship

$$\bar{m} = \frac{\pi \rho (\bar{d})^3}{6} \times 10^{-9}$$

$$= 5.236 \times 10^{-10} \rho(\bar{d})^3 \ ;$$

where,

ρ = density of spray material in grams per cubic centimeter.

For the example shown in figure 17, where the density of the spray material is 1.067 grams per cubic centimeter, the entry in the first column of row B is

$$\bar{m} = 5.236 \times 10^{-10}(1.067)\ (23.0)^3$$

$$= 6.796 \times 10^{-6} \text{ milligrams}$$

Repeat the calculation for each size category and enter the result in the appropriate column of row B.

Row C, sum of drop densities by size category

The sum of drop densities by size category is obtained by summing the drop density in each size category over all the cards analyzed in the swath. In the example shown in figure 17, the result for the first column in row C is

$$2.562 + 5.500 + 8.625 + 5.500 + 1.1000 = 23.187\ (23.19)$$

where 2.562 is the drop density from card 43, size category 1, 5.5 is the drop density from card 46, size category 1, etc.

Repeat the summation procedure for each size category and enter the results in the appropriate column of row C.

Row D, average drop densities by size category

The average drop density in each size category is obtained by dividing the sum of drop densities in row C by the number of cards included in the analysis (5 in this case). For the example shown in figure 17, we get

$$\frac{23.19}{5} = 4.638$$

which should be entered in the first column of row D for size category 1.

Repeat the calculation for each size category and enter the result in the appropriate column of row D.

Row E, cumulative drop densities

The cumulative drop densities shown in row E of figure 17 were calculated from the average densities recorded in row D. The cumulative density recorded in each size category column of row E is the cumulative sum up to and including the average drop density recorded for that size category in row D. For the example shown in figure 17 in row E for category size 3, the cumulative drop density is

$$4.638 + 8.976 + 7.362 = 20.976 = 20.98.$$

Continue the summation procedure across row D until the cumulative density for each size category has been calculated and recorded in the appropriate column of row E. Also, enter the cumulative sum for the largest category (32.64 in figure 17) in the total columns of row E.

Row F, cumulative percent of drop densities

The cumulative percent of drop densities is calculated for each size category by dividing the cumulative drop density for each category in row E by the cumulative drop density in the total column of row E and multiplying by 100. For the example in figure 17, the cumulative percent in the first column of row F for size category 1 is

$$\frac{4.638}{32.64} \times 100 = 14.21 \text{ percent.}$$

Calculate the cumulative percent of drop densities for every size category and record the result in the appropriate column of row F.

Row G, average deposition by size category

The average mass deposition by size category is calculated by multiplying the mean drop mass in a given size category in row B by the corresponding average drop density in row D. Thus the average deposition for category 1 in row G of figure 17 was obtained from

$$(6.796 \times 10^{-6})\ (4.638) = 3.152 \times 10^{-5} \text{ milligrams per square centimeter}$$

Complete the calculation for each size category and enter the results in the appropriate column of row G.

Row H, cumulative mass

The cumulative mass for each size category shown in row H of figure 17 is calculated from the average deposition values recorded in row G. The cumulative mass recorded in each size category column of row H is the cumulative sum up to and including the average deposition recorded for that size category in row G. In figure 17 the cumulative mass for row H, size category 3, is

$$3.152 \times 10^{-5} + 2.862 \times 10^{-4} + 8.194 \times 10^{-4} = 1.137 \times 10^{-3}.$$

Continue the summation procedure across row G until cumulative mass for each size category has been calculated and recorded in the appropriate column of row H. Also enter the cumulative sum for the largest category (1.207×10^{-2} in fig. 17) in the total column for row H.

Row I, cumulative percent of mass

The cumulative percent of mass is calculated for each size category by dividing the cumulative mass for each category in row H by the cumulative mass in the total column of row H and multiplying by 100. In figure 17, the cumulative percent in the first column of row I for size category 1 is

$$\frac{3.152 \times 10^{-5}}{1.207 \times 10^{-2}} \times 100 = 0.26 \text{ percent}$$

Calculate the cumulative percent of mass for each size category and record the result in the appropriate column of row I.

FOLIAGE EXAMINATION
John W. Barry

The following procedures are presented for use in examination of coniferous foliage (needles) for the purpose of counting and sizing spray droplets.

1. Needle samples must be collected with care to avoid smearing and dislodging the stain from the needle surface. The needle collection method is shown in figure 19.

2. Samples should be stored under refrigeration to reduce needle drying, condensation, fungal growth, etc.

3. Counting should be accomplished with a zoom type dissecting stereomicroscope with an eyepiece reticle. Artificial lighting should be used. The illuminating device should be capable of increasing or decreasing the light intensity to improve stain contrast as required. Use an ultraviolet light to count fluorescent stains.

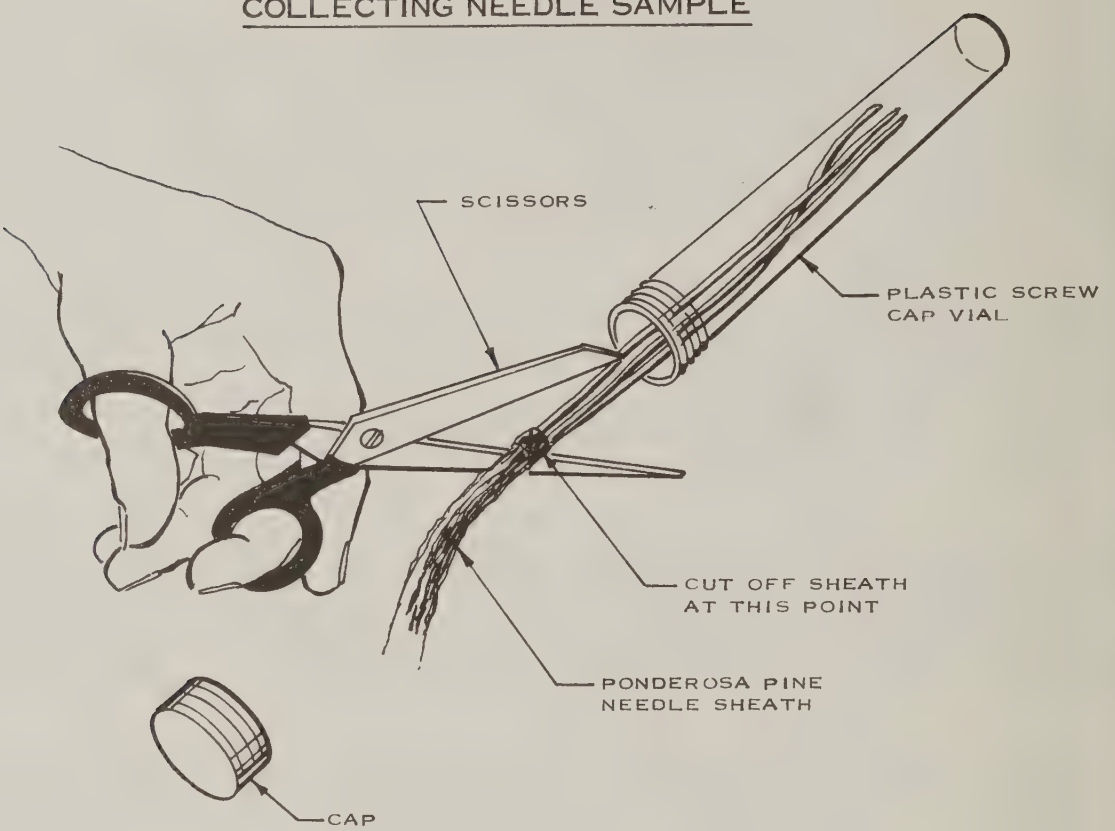
4. Magnification should be between 23 and 30 power. The eyepiece gives 10 power magnification and the scope will zoom to 2.3 to 3 power, depending on the model used.

5. Calibrating the eyepiece is very critical. This is accomplished by placing a calibration slide in a petri dish and then placing the dish on the stage of the microscope. Determine the smallest increment in micrometers on the calibration slide and aline the slide with the scale in the eyepiece. For reference it is a good idea to make a drawing of the eyepiece scale alined with the scale on the calibration slide. You may find it necessary to change the zoom dial to a lesser magnification, i.e., to 2.3, to make this alinement. When you are satisfied that the slide is alined with the eyepiece scale, have at least one other person check it by comparing it with the calibrated slide. Tape the zoom dial to prevent movement and changes in the magnification.

6. It is best to work in pairs, one person counting while the other person records the data on the needle data sheets (fig. 20). Frequently alternating assignments between two people lessens fatigue.

7. The samples will probably be in a tube or bag. Remove the 2-inch branch tip sample and select the first ten 1-year-old needles from the tip below the new needles. Try to select needles that are approximately the same length. Do not select broken, immature, or eaten needles. Remove the needles with forceps and place them in the same petri dish used to calibrate the microscope and begin counting. Keep account of the sample number and maintain a clean work area.

COLLECTING NEEDLE SAMPLE



1 PLACE VIAL OVER THE 3 CLUSTERED NEEDLE WITHOUT TOUCHING THE NEEDLES. CUT THE NEEDLES AT THE UPPER END OF THE NEEDLE SHEATH AND SECURE THE CAP.

2 LABEL THE VIAL BY PLOT, TREE NUMBER, AND DATE.

3 STERILIZE THE SCISSORS WITH CIGARETTE LIGHTER PRIOR TO COLLECTING THE NEXT SAMPLE.

Figure 19.--Methods of collecting needle samples to avoid direct contact with fingers. Shorter vials would be used for spruce and fir needles.

NEEDLE DATA COUNTS

PROJECT:
TRIAL NO.
TRIAL DATE:
COUNTING DATE:
COUNTER:
MAGNIFICATION:

TREE NO.	SAMPLE NO.	UPPER	LOWER	STAIN SIZE	SMEAR	NEGATIVE	REMARKS

Figure 20.--Data sheet for recording needle counts.

8. Examine the entire length of the needle including both surfaces. Record separately on the data sheet the number of stains observed on each side of the needle entering zeros when no stains are observed. Appropriate remarks should be included on the data sheets.

9. Some stains will not appear as perfect circles. Due to the nature of the formulation, the angle of impact, and the velocity of impact, the drops may run or smear on the needle surface. This will be particularly noticeable on the needle margin and on the underside along the rows of stomata. The rules for measuring a stain are:

    a. If the longest axis is more than two times the shortest axis, do not measure the stain. Do, however, indicate on the data sheet that the stain is a smear.

    b. *Always measure the smallest diameter of the stain.*

10. Occasionally it will be obvious that the drop shattered when it hit the needle or slid off the needle. Count these as smears. After a little experience, you will be able to determine whether a drop slid off the needle leaving traces of the formulation or that it shattered making many small droplets. It is important to insure that the satellite droplets are not counted as drops.

11. Be consistent in your procedures.

Insects can be examined for the presence of spray drops following the procedures outlined above. The surface structure of insects, however, will obscure or otherwise make the drops invisible unless the drops fluoresce. Fluorescent particles are readily visible on spruce budworm larvae when an ultraviolet light is used in conjunction with a stereomicroscope following the procedures developed by Himel (1969) and Barry et al. (1974).

FOLIAGE WASHING
George P. Markin

The technique for analyzing spray deposit by washing foliage is basically the same as the procedure already described for analyzing deposit from aluminum plates. The technique has been used successfully for both coniferous[2/] and deciduous forest foliage (Maksymiuk and Orchard 1975). The procedure consists of removing a foliage sample from the tree immediately after spraying, washing the deposit from the sample, analyzing the wash solution fluorometrically, and then converting the results to express the deposit in terms of micrograms of insecticide per gram of foliage, per needle, per square inch of leaf surface, etc.

Field procedure.--Extendable pole pruners are used to collect three or more foliage samples from each sample tree, at the same height and location as the insect population being sampled. Samples usually consist of 10-inch branch tips for coniferous trees or 25 leaves from a deciduous tree. After they are collected, samples are carefully examined to make certain they contain no insects. The accidental introduction of even one feeding larva into a sack can result in the larva's devouring the whole sample before the sample reaches the lab. The samples from each sample tree are placed in an ordinary brown paper bag which is stapled shut. Foliage is arranged so that it lies flat on the side of the bag; the bag is then folded flat to make as compact a package as possible. Bags from each plot are usually combined in loose bundles. When stored in a dry room for several weeks or more, foliage usually desiccates naturally and is dry enough for analysis by the time it reaches the lab.

Laboratory analysis.--In the laboratory, the drying needles are removed from the twigs, mixed together, and a subsample removed from the mix. The subsample can either contain 100 needles or 1 gram of dry foliage. If deposit is to be expressed as volume weight per weight of dry foliage, the foliage samples should first be further dried to a uniform level in an oven. A small cork borer is used to remove 1 cm^2 disk from leaves. Forty of these disks (40 cm^2) of the foliage from each tree are used as a sample. The dried foliage is placed in a 150-ml Erlenmeyer flask and 10 ml of the appropriate wash solution is added (30 percent ethylene for oil-base insecticides, distilled water for water-base insecticides). The combination is agitated on a mechanical shaker for 15 minutes. Excessive washing and stronger solvents are not advised since they may remove pigments from the foliage which can confuse the fluorometric analysis. The wash solutions are analyzed with a fluorometer as described in analyzing aluminum plates.

[2/] Neisess, J., B. Maksymiuk, R. A. Waite, and M. J. Haskett. 1973. Comparative studies of spray deposit distribution of Zectran and pyrethrins used against the Douglas-fir tussock moth in 1972. Unpublished progress report, 73-1, Aerial Applications Research Work Unit. On file at Forestry Sciences Laboratory, Corvallis, Oreg.

Standards of untreated foliage collected from the plots before spraying are used to give a background reading for the foliage which can then be subtracted from the reading obtained from the washed foliage. A tank sample collected from the aircraft just before spraying is necessary to accurately determine the amount of dye in the spray solution so that the exact ratio of insecticide to dye can be determined. Knowing the amount of dye obtained from the foliage sample, the weight (or size) of the foliage sample, and the ratio of insecticide to dye, it is possible to express recovery as amount of insecticide per gram of foliage; amount of insecticide per needle or per 100 needles; amount of insecticide per given foliage area (micrograms per square centimeter or parts per million of insecticide).

Comments. Preparation of the foliage sample and washing and analyzing it not only are time consuming but also demand a very high degree of accuracy. As a research tool, however, this technique is believed to be an accurate method of determining the actual amount of spray reaching the target insect. The samples can be collected at the same point where the population of target insects is being studied, i.e., if the budworm population is being sampled at midcrown in the tree, foliage samples for analysis can be collected at the same location. Although foliage washing is not a suitable technique for deposit assessment on operational projects, it is probably the most accurate and useful tool for the researcher for correlating mortality with spray deposit.

COLLECTION PLATES
John Neisess

Some type of fluorometer is used for the analysis of the spray residues collected on aluminum plates. Two models currently being used by Forest Service laboratories are the Turner model 110 Fluorometer and Turner model 430 Spectrofluorometer. Almost all major manufacturers of scientific equipment make fluorometers or spectrofluorometers. The advantage of the spectrofluorometer is the ability to set the excitation and emission wavelengths for a particular dye. Fluorometers use different filters to achieve the same effect, but finding the proper filter combination may prove difficult and time consuming. The minimum detectable sensitivity of these instruments is about $1x10^{-10}$ grams per milliliter, which in a water solution is equivalent to 0.1 part per billion. The sensitivity is dependent on the solvent system, fluorescent dye, and background or naturally occurring fluorescences.

Absolute dye concentrations are obtained from meter readings with standard calibration curves. To make a standard curve, standard solutions of known dye concentration are made by diluting a field formulation which contains a dye concentration of $1x10^{-3}$ g/ml (field dose). Separate standard curves should be made for each sensitivity setting on the fluorometer. Three replicates of each dilution (concentration) are made for each curve. Dye concentrations should cover the range of $1x10^{-10}$ to $1x10^{-6}$ g/ml. Samples should always be measured on the most sensitive range of the instrument without exceeding the available 100 scale divisions. The preparation of standard solutions should start with the total formulation since any additives that may affect the fluorescence will be included in all the dilutions. Figure 21 illustrates the standard curve for the 100X range of the Turner model 430 Spectrofluorometer. The formulation was 8 billion international units/gal of Dipel 36B mixed with water and the dye was Rhodamine B extra S. Linear regression lines are fit to the standard curve data by conventional least squares methods. The estimated errors for calculations based on these curves are less than 6 percent of the values used as independent variables.

Since some formulations may contain sticking agents, the efficiency of washing must be determined. A microapplicator is used to apply five replicates of 5-10 microliters of formulation (e.g., five 1-µl drops) to the aluminum plates and comparable volumes to 10-ml volumetric flasks.

The volumetric flasks are brought to volume with the solvent which will be used to wash the plates. The deposit on the plates is allowed to dry for 48 to 96 hours and is then washed from the plates by the technique described below. The fluorescence of the wash solutions from the plates and volumetric flasks is measured with the fluorometer and the dye concentrations are determined from the calibration curve. The percent recovery values are computed as follows:

$$\text{percent recovery} = \frac{\text{g/ml from aluminum plate}}{\text{g/ml from volumetric flask}} \times 100.$$

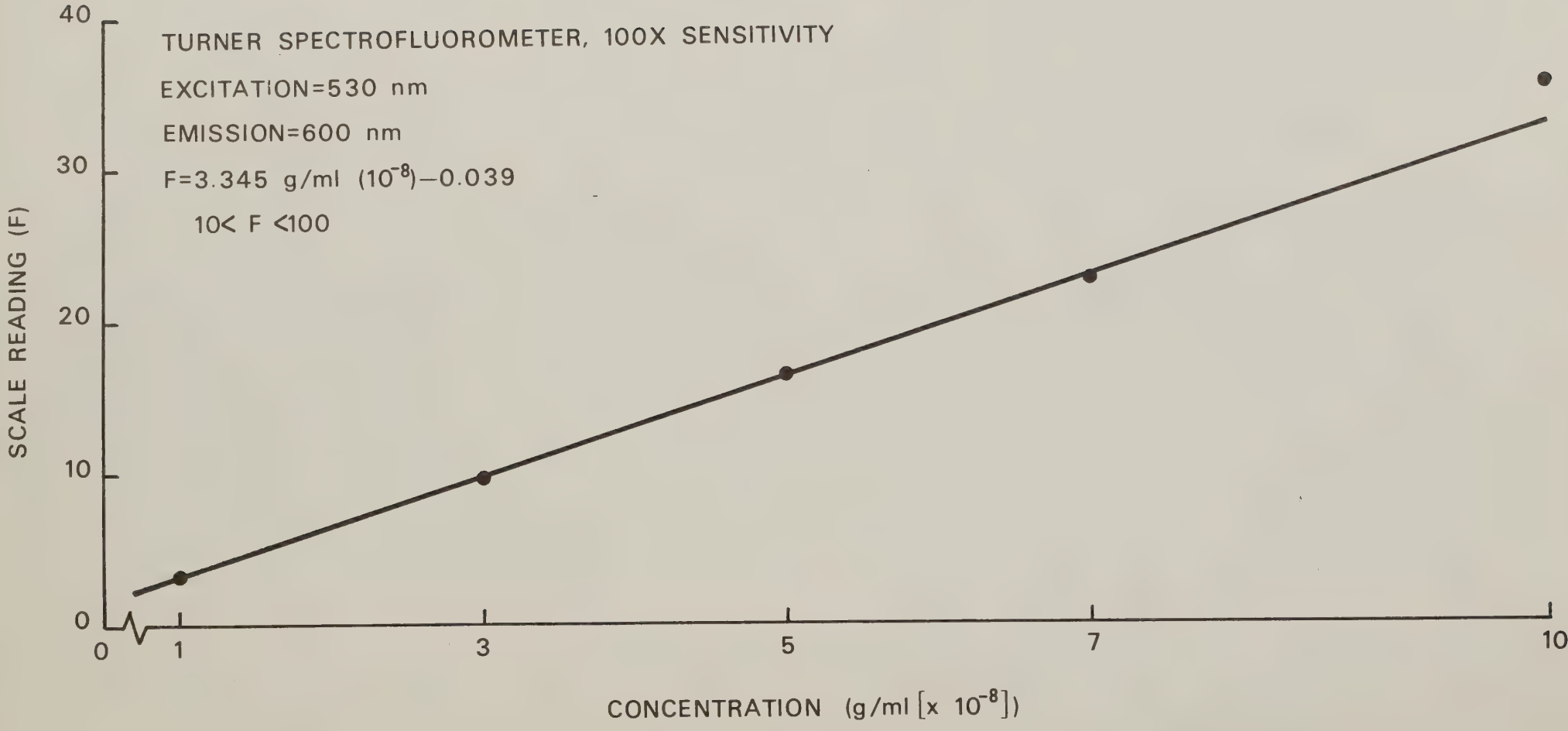


Figure 21.--Standard calibration curve for Rhodamine B extra S mixed in an 8 billion international units/gal Dipel 36B-H_2O mixture.

For processing the aluminum plates, a holder has to be built to hold a plate in an almost upright position. The plates are positioned on the holder so that all of the wash solution will run off one corner. A volumetric flask and glass funnel is placed under this corner to catch the wash solvent. The aluminum plate is uniformly sprayed with the wash solvent, using an Erlenmeyer type chromotography sprayer (fig. 22). The wash process continues until the volumetric flask is about full or until the deposit is removed from the plate. The liquid in the flask is brought to volume, and the fluorescence of the solution is measured. The dye concentration is determined from the proper standard calibration curve. The volume of spray on the plate (gallons per acre) is determined by the following equation:

$$\text{gal/acre} = \frac{(\text{g/ml dye washed from plate minus background values}) \times \text{ml of wash} \times \text{ft}^2/\text{acre}}{\text{g/gal dye in formulation} \times \text{ft}^2/\text{plate} \times \frac{\text{percent recovery}}{100}}$$

The background is determined by placing plates in the field in the same manner as those used to collect deposit. The background plates are collected and stored just prior to the spray applications. The background plates are washed by the usual procedure and fluorescence readings are converted to dye concentration equivalents from the calibration curves. Background values normally range from 2×10^{-10} to 1×10^{-9}, depending on the conditions of the experiment, dye, and solvent.

If a nonfluorescent dye has been mixed with the spray, deposit residues collected on aluminum plates can be assessed by quantitative absorption spectroscopy methods (Yuill and Secrest 1966). Quantitative absorption spectroscopy is not as sensitive as fluorometric analysis and should not be used to measure drift or very low deposits such as those found in areas that were skipped or missed.

As with fluorometric analysis, a calibration curve must be prepared from a series of standard solutions to determine the relationship between absorbance and concentration. As before, the standard solutions should approximate the overall composition of the actual deposit samples and should cover the expected range of concentrations. Deposit residues should be washed from the plates with the same equipment and techniques described for fluorometric analysis. Since all instruments have their own peculiarities, the operators' manual should be consulted for instrument setup and measurement of samples.

Figure 22.--Plate washing apparatus, including chromotography sprayer, plate holder, funnel, and 10-ml volumetric flask.

ANALYSIS TECHNIQUES FOR AIR SAMPLING DEVICES

Norman Akesson and R. E. Cowden

Air sampling devices are used to determine the airborne burden (particles below 50 to 75 μm). These particles can be airborne for significant distances because of air turbulence, even though Stokes' law suggests they would fall out if perfectly still air conditions existed.

Thus air sampling may be essential for a research project on adulticiding or flying insect contact, or for measuring airborne drift. Air sampling can also be used as a measure of the material being moved through and with the airmass in which spray was released.

Any of the air sampling devices (light scatter, filters, and various impactors) may be used for this type of monitoring. It must be recognized that light scatter is most effective on drops below 5-10 μm and impactors function most effectively for sampling drops generally smaller than 100-μm diameter. The filters will collect the broadest drop size range from the largest airborne particles to 0.01 μm. For vapor phase, solvent bubblers and absorbent dry chemicals are used. The following describes some frequently used services and techniques for air sampling.

ROTATING COLLECTORS

Rotating rods, wires, slides, and other forms have been used to evaluate airborne material concentration but these devices have severe limitations in that most are capable of collecting only a fraction of the particles in a practical range of 20- to 100-μm diameter. Thus, statistical means, which can easily introduce large sample errors, are used to arrive at the total air burden.

COLLECTION FILTERS

Glass fiber, gelatin, and cellulose filters can be obtained in a variety of pore sizes and may also be soluble or nonsoluble in the specific chemicals used to strip or dissolve the filters for chemical analysis of tracer chemicals. Filter efficiency is excellent, up to 95 percent for drops down to 0.01-μm diameter. Air volumes up to 50 ft^3/min may be used; this provides a high sample rate for evidence of low concentrations of materials. Some filters can be examined for drop size as well as for the gravimetric evaluation of tracer mass collected. Other multistaged filters separate different particle sizes on several successive stages of filter papers (from 0.5- to 100-μm), much as the Cascade Impactors do.

SPRAY ASSESSMENT SAMPLING EQUIPMENT

1. A Hi-Volume Staplex Air Sampler (fig. 23) may be used with Gelman Type A-E fiberglass filters. This sampler draws approximately 24 ft^3/min with about 98 percent collection efficiency for particles as small as 0.05 μm. The sampling area is 9.62 in^2 or 62.1 cm^2.

2. Millipore and nuclepore-formed filters of very specific pore size (0.1- to 100-μm diameter) are available in several overall sizes. The 47-mm diameter filters with a pore size of 0.8 μm were used with the vertical sampling tower and operated at a sampling rate of 1.62 ft^3/min. The samplers were set at 4, 8, 12, 16, 24, 32, 42, 48, 56, and 64 feet above the ground, and both drop sizing counts and quantitative analyses of the pesticide or tracer materials were made.

3. The Anderson Cascade Hi-Volume Air Sampler uses four perforated Type A glass-fiber filter disks with an 8x10 Type A glass-fiber backup filter.

   This unit draws approximately 20 ft^3/min with a particle size range of 7 μm and above, 3.3 to 7, 2.0 to 3.3, 1.1 to 2.0, and 0.01 to 1.1 μm at the smallest end. The sampling area is 2.81 in^2 or 18.1 cm^2.

4. The Weather Measure Hi-Volume Cascade Air Sampler uses Type A fiberglass filters, has a sampling rate of 20 ft^3/min, and has six stages: 8.2 and up, 3.5-8.2, 2.1-3.5, 1.0-2.1, 0.5-1.0, 0.01-0.5 μm. The sampling area is 2.81 in^2, 18.1 cm^2.

IMPACTORS

Cascade Impactors separate the drops or particles collected in four to eight stages, based on the air velocity passing through the impactor orifices. Large droplets (50-100 μm) are collected by the first stage with low air velocities. Small droplets (2-5 μm) are collected by the high velocity stage 4.

Drops from each stage may be counted and sized by microscope; or, under constant conditions of airflow, each stage may be worked for dye or tracer collected. The percentage of dye indicates the number of drops collected at each stage for its particular size range.

Sampling the air in the spray area will give a drop size frequency analysis of the air and will indicate approximate amounts of released material, by weight or volume, in the spray area.

Air sampling should always be accompanied by fallout collection to evaluate the deposit of material as well as that transported in the air (fig. 23). In this way a mass balance may be approximated from any spray application equaling the amount of material applied to the amounts deposited in the spray swath and amounts lost downwind which become the fallout and airborne portions. Since these latter amounts are usually small in relation to that deposited in the swath, simply subtracting the swath deposit from the amount released and taking this as the downwind loss is inadequate.

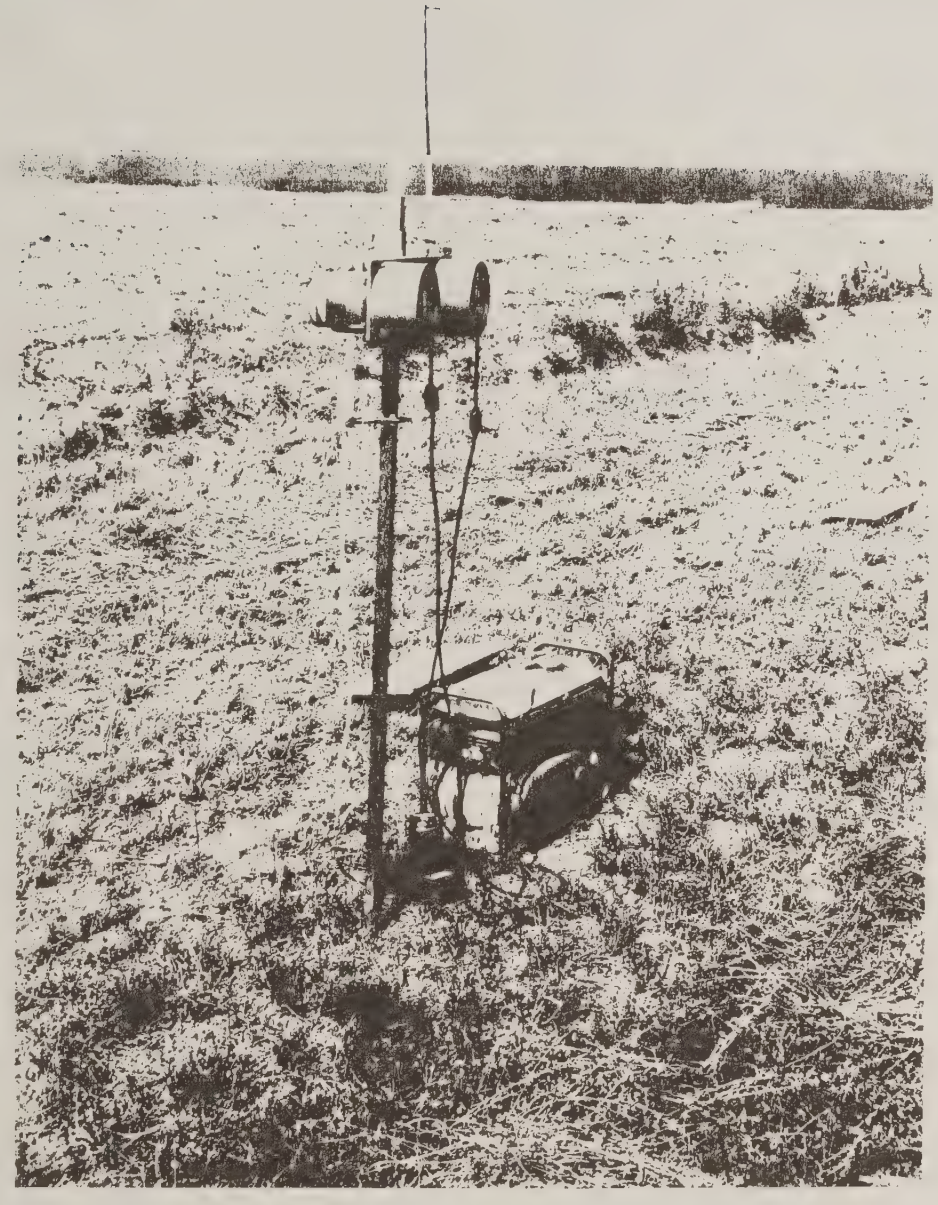


Figure 23.--Sampling equipment used by University of California (Davis) for air concentration and deposition of pesticide sprays. Station consists of millipore filters with high volume pump, Mylar® film for deposition, and Cascade Impaction sampler.

This evaluation of the deposit of chemicals onto both target and nearby nontarget areas has become increasingly important in pesticide application. Because of the potential hazard to people, wildlife, livestock, or crops, highly sensitive means for determining the amount of chemical have become necessary. These are of the order or parts per billion or nanograms of total sample. The analysis of pesticide chemicals is not always the best method because of expense, potential use hazard, complexity of analysis, or lack of sensitivity in some cases for specific chemicals. Research has been conducted by the Department of Agricultural Engineering, University of California at Davis, to develop nontoxic, sensitive tracer techniques for determining the micro to nanogram amounts of chemical deposited on plant targets or artificial collectors or transported in the air to distant areas.

TRACER SELECTION

The selection of the type of tracer to be used is an important first step. Things that should be considered are sensitivity, stability, and compatibility with the material to be used in the applications.

Fluorescent dyes, such as Rhodamine B which comes in both water and oil soluble form, are used extensively. The advantages are good sensitivity to 1 part per billion, excellent stability while in solution, and red dye characteristics which show up well for drop size analysis on glass slides or Kromekote^{R} cards. Solution concentration of 1 pound of dye per 100 gallons of water is sufficient for both qualitative and quantitative analyses. Some disadvantages encountered with dyes when trying to quantitatively determine the amount of material that has been deposited on the target areas is the degradation which occurs from solar radiation and the background contamination from dust or plant tissues. These factors tend to mask the fluorescence of the dye. Equally sensitive and less subject to decay are the salt tracers. With the improvements made in atomic absorption spectrophotometry, the use of salts has become highly effective. Detection limits as good as that attained by fluorometry or by gas-liquid chromatography for pesticides are easily attained. Salt tracers have the added advantage of not being photosensitive and, if carefully selected, have little problem with background contamination. Several different salts such as manganese sulfate and strontium chloride can be mixed in the same solution and then analyzed separately. This allows several types of applications on the same collection substrate. Dye may be added to the solution if a visual analysis is desired. A concentration of 1 to 10 pounds per 100 gallons is sufficient for most applications. A word of caution: When salts are added to emulsions they may upset the emulsion and cause it to break.

An excellent collection surface for sampling the fallout of material is 5 mil Mylar® film. The sheets of Mylar® film should be cleaned separately in 1-gallon widemouth plastic jars and the rinse solutions checked for cleanliness in the instrument to be used for the analysis. The sheets can then be removed from the jars with tweezers, cut into 6- by 8-inch strips, and stapled to a 12- by 24-inch celotex board that has been covered with a 12-inch by 30-inch plastic bag. Two boards are then laid face to face and placed in another plastic bag and heat sealed until they are used in the field. The jars are also sealed and put in the boxes until used.

After being exposed in the field, the plastic sheets are immediately placed in the jars and returned to the lab where 50 to 100 ml of solvent (depending on tracer used) is placed in each jar and the tracer or pesticide stripped from the sheets.

In summary, tracer salts offer a low cost, highly sensitive, rapid analysis technique and, because they are nontoxic, can be used on test locations where the actual pesticide may be prohibited or may be a hazard.

SECTION VIII

Data Analysis and Reporting Pilot Control and Operational Projects

ASCAS—AUTOMATIC DATA PROCESSING PROGRAM

John W. Barry

USDA Forest Service Forest Insect and Disease Management (FI&DM) is implementing an automatic data processing program called ASCAS (automatic spot counting and sizing program).

This program was adopted by FI&DM because of the need for a rapid, accurate, and standard method of processing spray deposit data obtained from deposition samplers, such as Kromekote® cards.

ASCAS was developed several years ago by the U.S. Army, Dugway Proving Ground (DPG), Utah, to assess spray droplets on Printflex cards, a card similar to Kromekote®. The ASCAS program was provided by DPG and has been modified by FI&DM Methods Application Group (Luebbe 1977) for FI&DM application.

Basically, the program needs punched cards containing identification and number of stains in the various size categories specified (16 at present). Through input to the program, including spread factor equations and specific gravity of the subject formulation, the stain diameters are converted to drops (spheres) and various output values are then computed, including mass median diameter (MMD), volume median diameter (VMD), number mean and number median diameters, number of stains per unit area and amount of mass per area. These values are computed and printed for each spray deposit card and summarized at higher levels, i.e., spray blocks.

Basic procedures are as follows:

1. Determine specific gravity and spread factor for each formulation.
2. Collect spray deposit sample from the field.
3. Identify cards with appropriate spray block number, tree cluster, tree, and position beneath the tree.
4. Submit spray cards to appropriate lab to be processed by the Quantimet®.
5. Determine parameters needed for the Quantimet® (drop size intervals and area of spray card to be counted). Parameters are dictated by lens size.
6. Process spray cards by the Quantimet®.
7. Obtain output data from Quantimet® (usually punched data processing cards and a listing of an analysis of each spray deposit card).
8. Process the data processing cards through the ASCAS computer program.
9. Extract data from printout, analyze data, and integrate data into the reports.

The entire process from field collection to ADP (automatic data processing) printout can be accomplished in a relatively short time. It is imperative that the project leader be aware of the sequence of operations and that he monitor each step closely.

One of the most annoying problems is to get the data in a form so that the summaries are meaningful. The computer program sorts the data by the identification from each spray card. The spray deposit cards must have proper identification as specified in section VII.

It also must be emphasized that the user must be alert to errors in the printout caused by incorrect input or mechanical malfunctions of the ADP system.

This program is very useful to both the researcher and those conducting pilot control and operational projects. The program provides a method of determining spray deposit and of understanding spray behavior over the spray area. When used in conjunction with insect mortality and meteorological data, the program provides a basis for understanding spray behavior and designing future experiments and control projects.

Details and documentation of the ASCAS program are provided in a FI&DM Methods Application Group report (Luebbe 1977).

The ASCAS printout of data output includes the following sections: (1) Introduction: file identification, titles tape or disk, number of samples analyzed; (2) Control cards (punch cards): formulation spread factor, density or specific gravity of formulation; (3) Size category data: stain and drop-size categories and ranges; (4) Raw data tabulation number of stains in each size category indicated on the printout for each sample; (5) Results for unit cards: drop-size data--mass median, mass mean, number median and number mean, drop density, and volume and mass data; (6) Results for all cards: summary of results of unit cards; Total summary: summary of number of counts and mass recovered in each drop-size category per square meter.

DATA ANALYSIS
Robert Young

Presented are the statistical analysis procedures for spray deposit data as it relates to insect mortality.

OBJECTIVE

The following are the reasons for analyzing mortality as a function of spray deposition:

1. To determine the effectiveness of the treatment on the target population.
2. To determine the effectiveness of aerial application.
3. To determine minimum dosages required to achieve a predetermined population reduction level.
4. To develop spray specifications (droplet size, VMD, number of droplets, spray mass, etc.) for future projects.

The relationship between spray deposit variables and mortality depends on control of the insect population. If the material tested was extremely effective, a good relationship usually occurs (fig. 24). If, on the other hand, the insecticide was not effective, the correlations would be low (see fig. 25).

DATA PREPARATION

Sampling procedures used to determine insect mortality involve destructive sampling. Insects used to estimate the prespray population levels are taken from a branch cut from the tree; therefore, the same insects cannot be used to estimate postspray populations. Sampling variation is reduced by aggregating the data to the tree or cluster level. Cluster data are used if tree clusters are the primary sampling unit. Tree data are used if trees are the primary sampling unit.

Since most designs in field experiments and pilot control projects use clusters, detailed cluster calculations are presented. A tree cluster is defined as the primary sampling unit within each block consisting of three to five trees. Two to four branches are sampled from each tree. Four spray cards are used per tree. Cluster level averages are computed by the following procedure:

1. Prespray population

$$Pre_i = \frac{\sum_{j=1}^{\text{number of trees}} \sum_{k=1}^{\text{number of branches}} \frac{(insects_{jk})(100.0)}{buds_{jk}}}{6}$$

j = 3 trees
k = 2 branches

expressed in insects per 100 buds. The data can be expressed in other forms if desired--insects per 15-inch branch, insects per meter of foliage, etc. The subscripts are 1 = cluster, j = trees, k = branches.

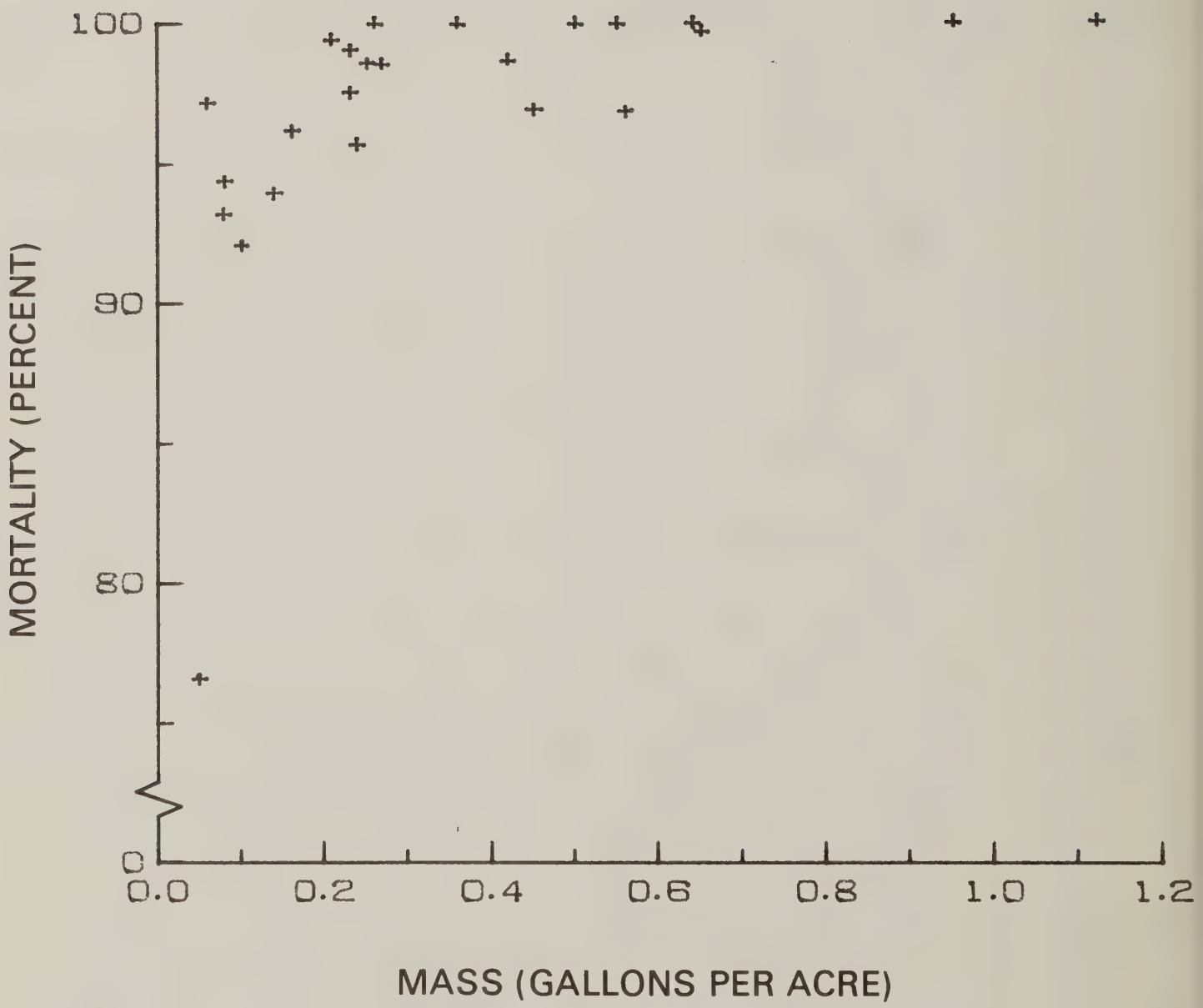


Figure 24.--Example of relationship between mass and mortality when insecticide was effective.

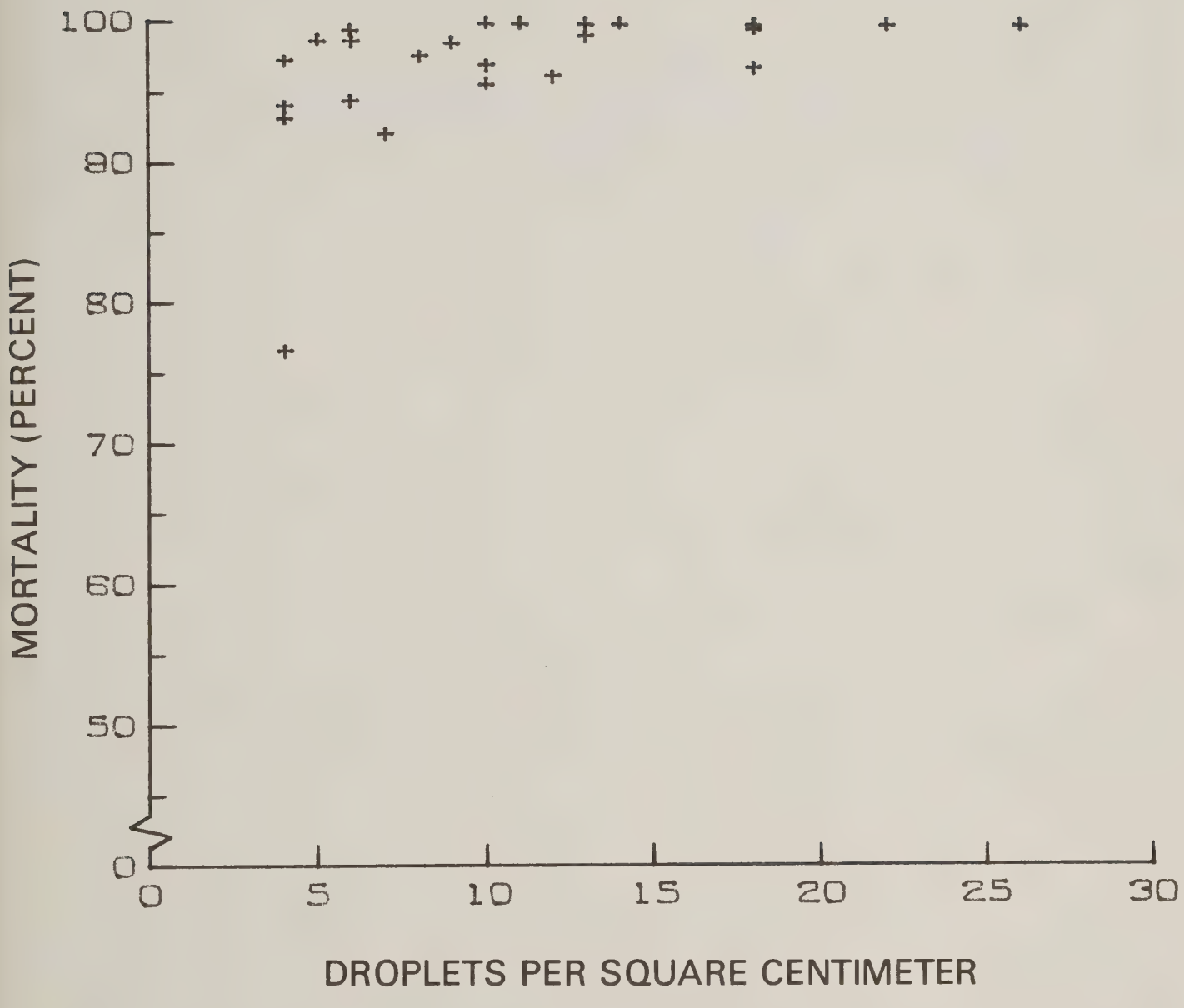


Figure 25.--Example of relationship between droplets per square centimeter and mortality when insecticide was effective.

2. Postspray population

$$\text{Post}_i = \frac{\sum_{j=1}^{3} \sum_{k=1}^{4} \frac{(\text{insects}_{jk})(100.0)}{\text{buds}_{jk}}}{12}$$

j = 3 trees
k = 4 branches

calculated for each postspray period.

Note that each branch has equal weight in the sample design. The cluster averages are the averages of insects per 100 buds of each branch. The cluster average should not be calculated by adding all the insects and all the buds in the cluster and then computing the insects per 100 buds.

3. Unadjusted cluster mortality for each postspray time period

$$\text{mort}_i = 1.0 - \frac{(\text{postspray population})_i}{(\text{prespray population})_i}, \text{ expressed}$$

in decimal form to three places 0.xxx or 1.000.

4. Spray deposit values at the cluster level come out of the ASCAS program for VMD, mass, and droplets.

A table is then prepared for input to the regression analysis:

Table X--Spray deposit and insect data

Cluster level for block _____

		Postspray			Mortality			Spray deposit		
Cluster	Prespray	A	B	C	A	B	C	VMD	Mass[1/]	Droplets
1										
2										
.										
.										
.										
25										

[1/] Mass can be expressed in oz/acre, mg/m^2, gal/acre, liter/hectare, etc.

REGRESSION ANALYSIS

1. Data modification: Some values from the data table will have to be edited before the data can be analyzed further. Listed below are guidelines:

   A. If the postspray level is greater than the prespray level, the resultant cluster mortality will be a negative number. Change all zeroes and negative numbers to 0.01.

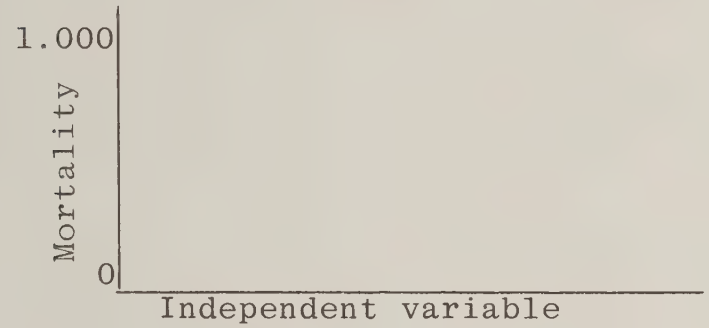
B. If any of the spray deposit data is zero, change all zeroes and negative numbers to 0.001.

The purpose of these changes is that in some regression programs both the independent and dependent variables must be greater than zero.

2. Regression models:

$Y = 1.0 - \frac{B}{X+B}$, where B is the unknown shape parameter, Y is mortality and X is the independent variable.

Properties and form of the model:



$0 < B < \infty$, B is small relative to the range of X.
when $X = 0$, $Y = 0$;
as $X \to \infty$, $Y \to 1.0$;
$0 < Y \leq 1.0$.

The development of the model was due to an analysis of raw data plots of the mortality (dependent variable) versus mass of spray deposit recovered (independent variable) and the number of droplets per square centimeter (independent variable). As spray mass or droplets per square centimeter on the cards increased, insect mortality also increased, approaching 1.0. The model provides a simplistic method for graphically seeing what level of mass of drops is getting the best results.

The purpose of the model is not to transform or manipulate the data to show a good "relationship"--namely a high R^2 value--but rather to see if the underlying relationship exists. The results can be used to evaluate effectiveness of the treatment and effectiveness of the application.

Method of estimating B.--Since the model is not linear in the parameter, formulas for the least square solution are not available. The criterion used to determine the "best" fit is the lowest sum of the squared deviations, $\sum_{i=1}^{n} (y_i - \hat{Y}_i)^2$ where Y_i is the predicted value from the model $Y = 1 - \frac{B}{X+B}$ and y_i is the value of the dependent variable for the set of B values. A successive approximation procedure is used to determine the lowest squared deviations:

Example:

Step	B	$\Sigma(y_i - \hat{Y}_i)^2$
1	0.5	3.583
2	1.0	2.767
3	1.5	2.601
4	2.0	2.779
5	2.5	3.152

The "best" B value would be 1.5 since 2.601 is the lowest squared deviation.

3. Regression models which can be linearized by transformations:

Methods.--Each of the nonlinear equations is transformed to an equation which is linear in its parameters A + B. The method of least squares is used to fit the transformed data. The models and transformations are given below:

Regression model	Transformed equation	Restriction
1. $Y = A + BX$	unchanged	none
2. $Y = A + B/X$	unchanged	$X > 0$
3. $Y = A + B\log X$	unchanged	$X > 0$
4. $Y = AX^B$	$\ln Y = \ln A + B\ln X$	$X > Y > 0$
5. $Y = X/(A + BX)$	$1/Y = A/X + B$	$X > Y > 0$
6. $Y = A(\exp)^{\frac{B}{X}}$	$\ln Y = \ln A + B(1/X)$	$X > Y > 0$

Goodness of fit statistics used to determine the "best" model is:

1. R^2, coefficient of determination;

2. residual error (standard error of estimate); and

3. maximum absolute residual.

Selection of the "best" model.--In order to compare the same chemical from block to block, the same model should be used. There is also some appeal in using the same model to compare chemicals used for an entire project.

Output tables.--Seven plots are presented as examples of the type of output generated from the regression model:

1. Figure 24 shows mass in gallons per acre vs. mortality. The plot shows the raw cluster data (25 points) for one spray block. This is an example of a good relation between mass and mortality. As mass increases, the mortality approaches or is 1.0.

2. Figure 25 shows mass in gallons per acre vs. mortality. The plot shows the raw cluster data (25 points) for one spray block. This is an example of a poor relation between mass and mortality.

3. Figure 26 shows mass in gallons per acre vs. mortality. The plot is for a spray block with 25 clusters. The model Y = A + B/X does a good job of fitting the data.

4. Figure 27 shows droplets per square centimeter vs. mortality. The plot is for the same spray block used in figure 26. The droplets per square centimeter for the same model do not give as good a relationship with percent mortality as does mass (gallons per acre).

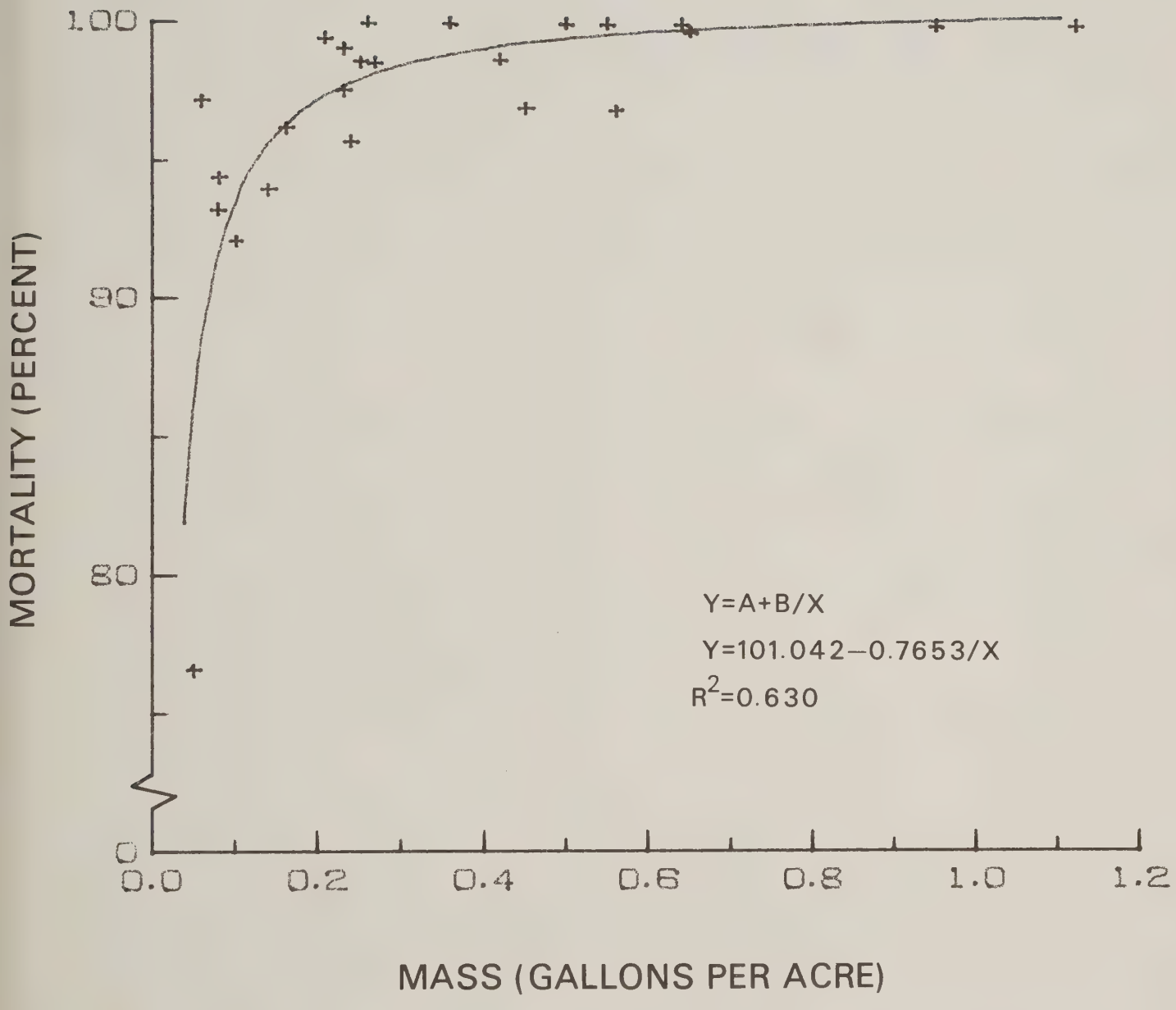


Figure 26.--Example of good relationship between mass and mortality.

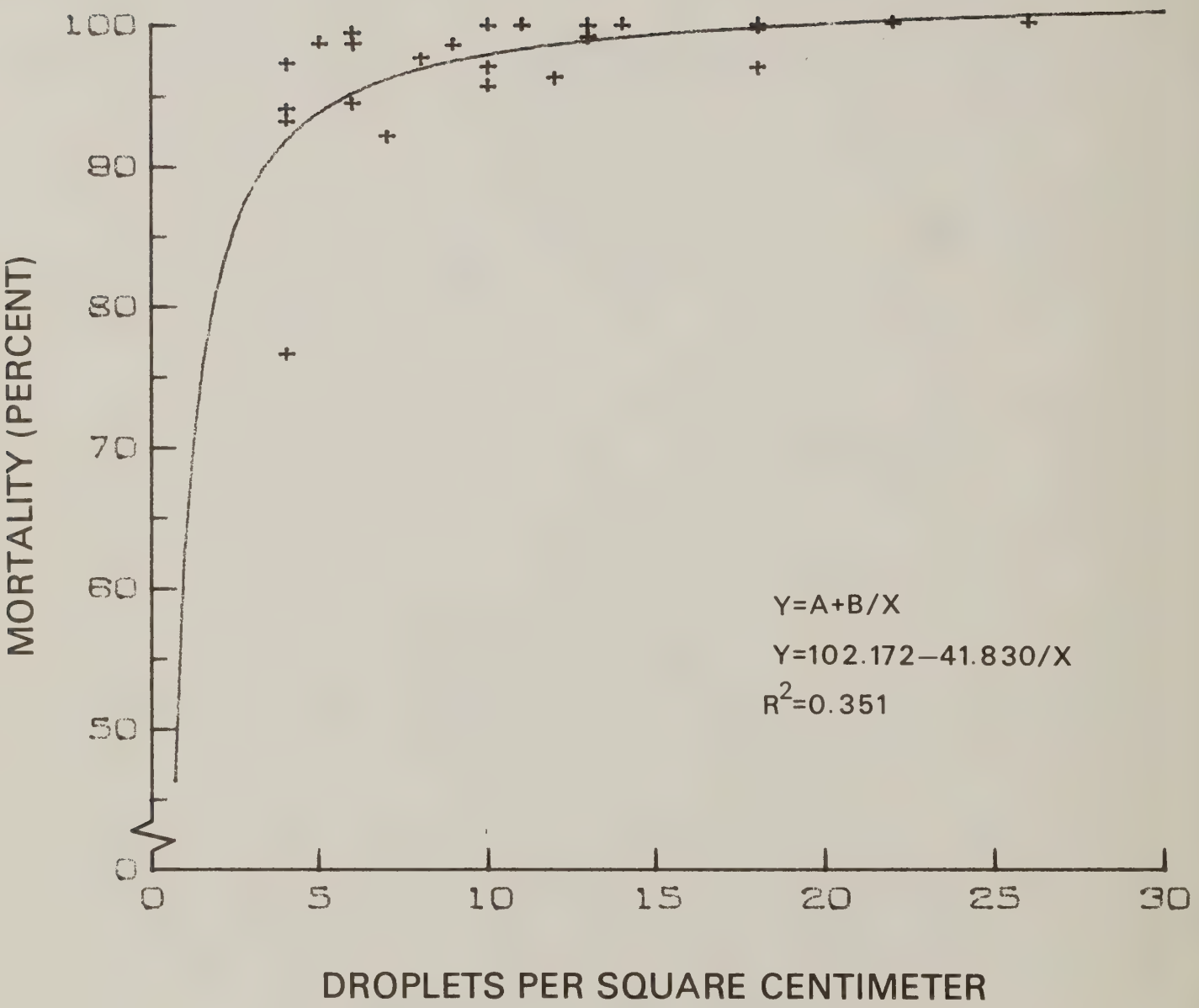


Figure 27.--Example of a good relationship between droplets per square centimeter and mortality.

5. Figure 28 shows mass in gallons per acre vs. mortality. The plot is for a spray block with 25 clusters. This is an example of a poor relationship between mass recovered on ground and mortality. Within the range of 0.02 to 0.04 gallon per acre, mortality ranged from 50 to 95 percent.

6. Figure 29 shows droplets per square centimeter vs. mortality. The plot is for the same spray block used in figure 28. Again there was some variation in the behavior of the droplets recovered in relation to mortality.

7. Figure 30 shows mass in ounces per acre vs. mortality. This plot is an example of a field experiment. Each point is for one spray block. There were four treatments with three replicates using one chemical at three dosage rates with checks; dosage rates were 1/2, 1, and 2 ounces per acre. This type of information shows percentage of mortality at different levels of dosage.

INTERPRETATION

The regression plots and/or scatter diagrams provide the user with information about how well a particular spray block performed. Answers to the following questions are possible:

1. What was the variability of spray deposition within each block?

2. What was the variability of spray deposition between spray blocks?

3. What was the effect on mortality within each spray block or between spray blocks due to spray deposition?

4. What is the minimum dosage rate needed to achieve a desired level of mortality?

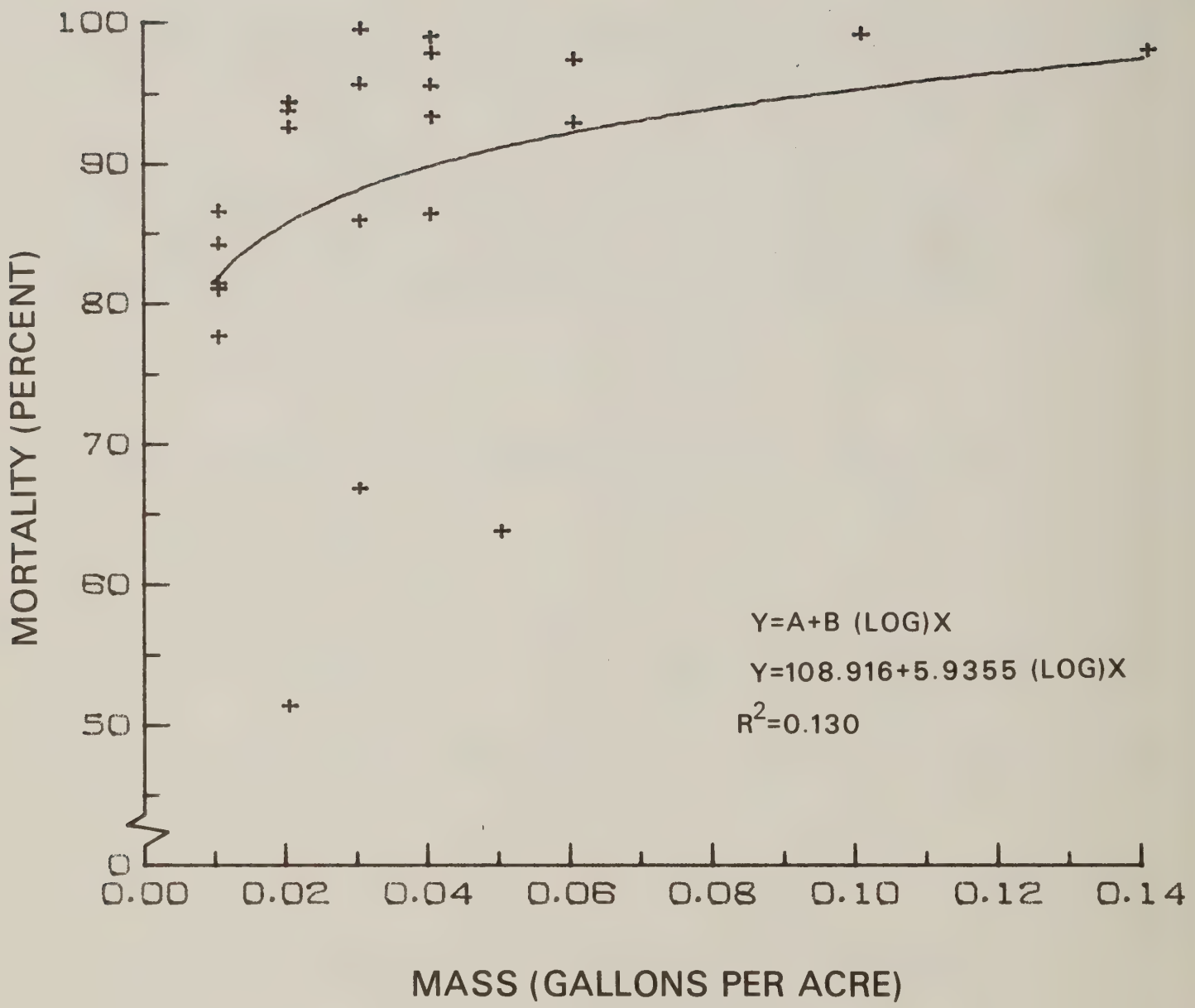


Figure 28.--Example of poor relationship between mass and mortality.

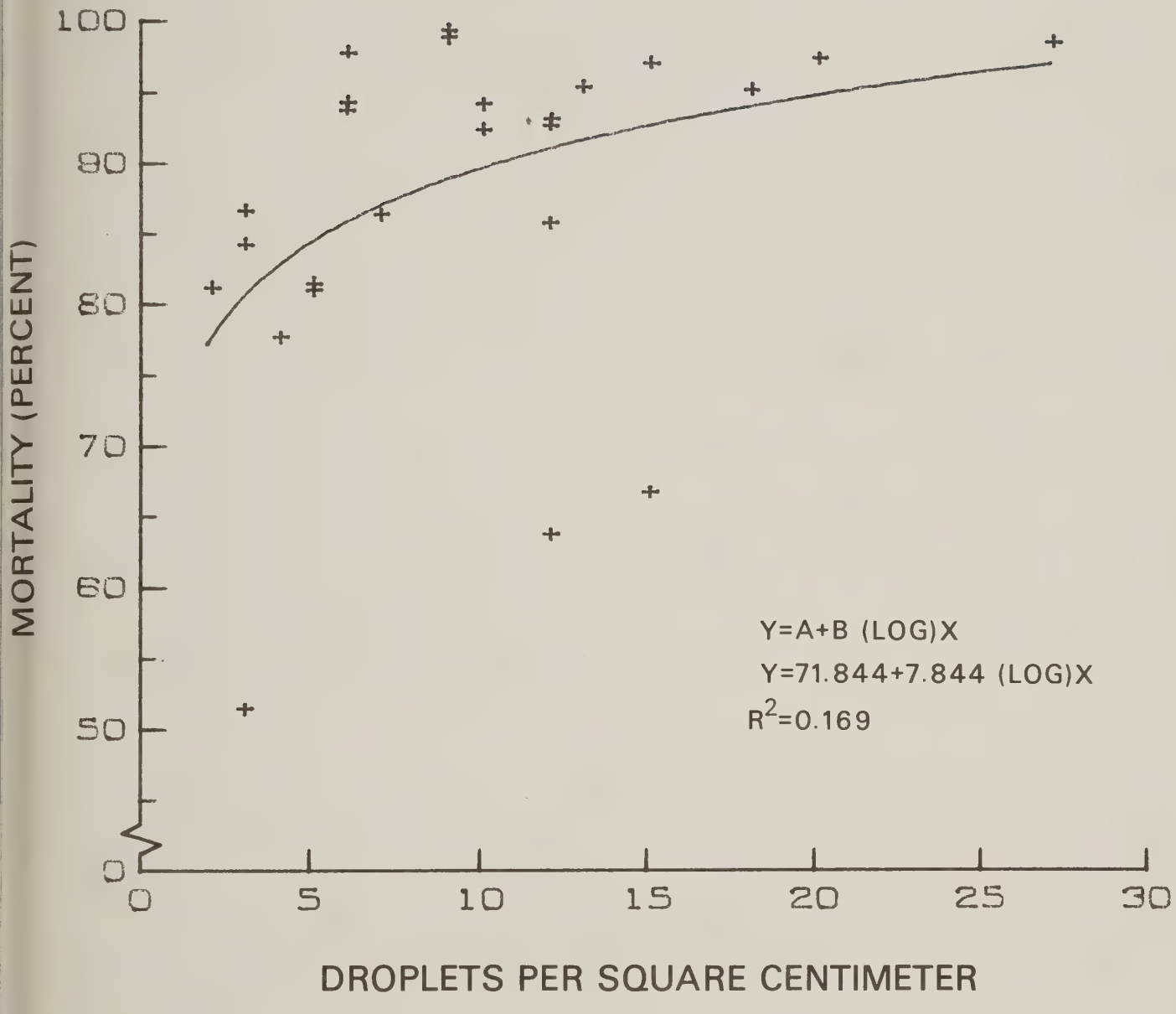


Figure 29.--Example of a poor relationship between droplets per square centimeter and mortality.

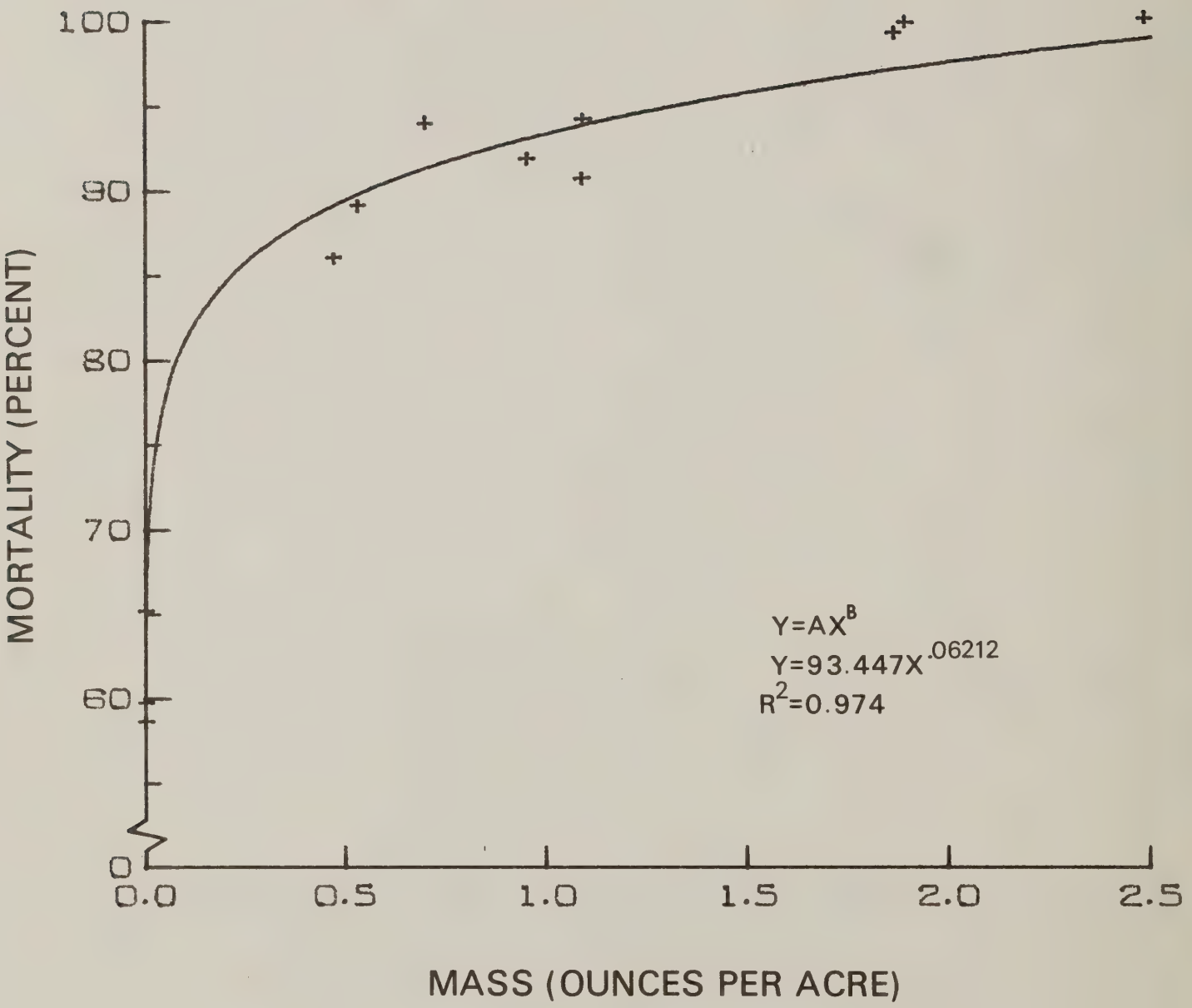


Figure 30.--Example of a good relationship between mass and mortality.

REPORTS
John W. Barry

Results of spray deposit sampling should be documented in detail. It is frequently necessary for engineers and scientists to review past spray data. Comparison of projects is possible only when there is some similarity in test design, data analysis, and reporting. What might seem unimportant to one person may be of great importance to the next. Data are costly in dollars and man-hours. Therefore, we are obligated to make the most efficient use of these data. All data should be bound together in the appendix of the project report or as a separate report. An example would be a researcher looking for canopy penetration data to determine how much of the spray enters the canopy as a function of drop size; if data on spray deposit recoveries in the open and within the forest are provided, he can estimate percent recovery of the spray. Proper organization of the report will make the report easy to read and will include all data.

Tables, graphs, and other illustrations should be used extensively for documentary and data analysis purposes.

ADP data listings should be included in the report. The standard printout list can be reduced in size and included in the report. It is important to include all data in the report.

A suggested report format is presented. The format is not as important as are the subsections within each major heading.

Abstract

The abstract should be a paragraph with one sentence answering the questions of how, what, when, where, and why of the test or project.

Introduction

The introduction should provide background information which led to the test. The reason for conducting the test should be given. A map showing spray block, sample positions, and meteorological stations should be included.

Purpose, Objective, Tasks

These should be briefly and clearly defined.

Scope

The scope should be written as a summary providing information about the number of trials, and the time and place of the test. By the time the reader gets to the scope, he should have an overview of the test.

Method

Insecticide.--Give physical properties of formulation and tank mix. Include registration label, spread factor, method of mix, and operational aspects of the mixing and filling operation.

Aircraft.--Describe type of aircraft; provide swath width, release height, speed, swath method used; include comments on the quality of application and a sketch map showing location of each spray swath.

Spray system.--Describe spray system, type of nozzles used, position of nozzles along spray boom, orientation of nozzles relative to slip stream or forward direction of the aircraft. Describe behavior of the spray system.

Site descriptions.--Describe the spray site, include type of terrain, forest characteristics (tree density, type species, stem density, canopies, ground cover, etc.).

Meteorology.--Describe meteorological instruments used and frequency of observations.

Sampling and sampling design.--Discuss the sampling design used, number and location of samplers, and purpose of each type of sampler.

Sampler assessment.--Describe the methods used to assess the samplers; this is particularly important if a variation of the standard method or a new method is used.

Results

Data analysis.--Describe method of analysis, and list data in tables and graphs. Place listings that are not of general interest in the appendix.

Meteorology.--Present meteorological data in tabular form. Describe meteorological effects on behavior of the spray cloud.

Aircraft operations.--Discuss all aspects of air operations; include diagram of spray swaths, turnaround time, pilot's comments, coordination, time of each spray run, calibration, aircraft characterization, etc.

Insecticide handling.--Discuss and evaluate methods used and possible problems encountered.

Recommendations

Make appropriate recommendations for improvement of future operations.

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Appendix

GLOSSARY OF TERMS

These definitions are as used in this handbook. They may or may not have a similar use in other publications.

ACTIVE INGREDIENT (active material)--an ingredient which provides stimulating or killing action. In pesticide use this is generally equivalent to the amount of technical material in a formulation.

AERODYNAMIC DROP--an airborne spray droplet.

AEROSOL--a colloidal suspension of solids or liquids in air, spray drops of less than 50 micrometers in diameter.

AIRCRAFT CALIBRATION--the process of establishing the flow rate from the spray boom to insure that the desired application rate is maintained.

AIRCRAFT CHARACTERIZATION--the process of determining the spray pattern, swath width, drop spectrum, spray density, spray mass, and spray volume produced by an aircraft spray system.

AIR DRAINAGE--general term for gravity-induced, downslope flow of relatively cold air; winds thus produced are called gravity winds.

APPLICATION RATE--usually refers to the amount of material applied per acre; for example, 1 lb of DDT per gallon of carrier per acre.

APPLICATOR--a person who directs a spray operation or one who actually does the spraying.

ASCAS (automatic spot counting and sizing)--automatic data processing program for analyzing spray deposit data.

ATOMIZE--to break up a liquid into fine droplets by passing it through an apparatus under pressure.

AVERAGE MASS DIAMETER--diameter of a droplet of average mass.

AVERAGE NUMBER DIAMETER--average drop size of all droplets sampled.

CANOPY PENETRATION--diffusion of the spray cloud into the forest canopy, usually expressed as a ratio or percent of the amount of spray recovered within the forest to that which is available at the top of the canopy.

CARDHOLDER--a device usually fabricated from plastic to protect and hold a Kromekote® card.

CLASSIFICATION OF DROP-SIZE SPECTRA (SPRAY ATOMIZATION)--there is no agreed classification for all purposes. Maksymiuk's classification for

aerial application of insecticides in forestry is as follows:

1. Aerosol spray--VMD of drops below 50 micrometers.
2. Fine spray--VMD of drops from 50 to 150 micrometers.
3. Medium spray--VMD of drops from 150 to 250 micrometers.
4. Coarse spray--VMD of drops from 250 to 350 micrometers.
5. Very coarse spray--VMD of drops above 350 micrometers.

COLLECTION PLATES--a collection surface such as aluminum or stainless steel plates or sheets for collecting liquid sprays in the field. The spray deposit is washed and assessed chemically.

CONCENTRATION--the percentage or amount by weight of a pesticide chemical in a formulation or when ready to use.

CUBIC FOOT PER MINUTE--ft^3/min.

DENSITY--specific gravity.

DEPOSIT CARDS--cards (i.e., Kromekote®, Sudan Black) used to sample spray deposit.

DEPOSITION DENSITY--amount of spray material which was recovered on deposit cards expressed in drops per unit area, volume per unit area, or mass per unit area.

DILUENT--a liquid or dust material used to water down or weaken the concentrated pesticide chemical so it can be safely and economically used.

D-MAX METHOD--a method of estimating VMD as a function of the five largest drops on a set of deposit cards.

DRIFT--the portion of a spray cloud which is not deposited within the target area.

DROP DENSITY--the number of deposited drops per unit area; for example, (drops per cm^2).

DROP SIZE--commonly expressed as drop diameter in micrometers.

DROP-SIZE SPECTRUM--range of drop sizes, usually involving characterization of drop size and number distribution as produced by various atomizing devices. Commonly used atomizing devices produce a range of drop sizes--the number of spray drops is inversely proportional to the drop size.

EFFECTIVE SWATH WIDTH--that portion of the swath width which meets the established criteria of drop density (i.e., drops per cm^2) and/or mass (ounces per acre).

EFFICACY--capacity of material to produce desired effects; effectiveness.

FORMULATION--insecticide mixture produced and delivered by the manufacturer. Once the formulation is diluted in the field, it is referred to as tank mix.

GAL/MIN (gallons per minute)--a measure of liquid moved by a pump.

INSECTICIDE--a substance or mixture of substances or biological agents intended to destroy insects.

KROMEKOTE CARD®--cover stock manufactured by the Mead Corporation, Dayton, Ohio, often referred to as a deposit card sampler.

LABEL--all written printed or graphic material attached to the immediate container of an economic poison.

MMD (mass median diameter)--the drop size diameter that divides the spray mass into equal parts; 50 percent of the mass is in drops below the MMD and 50 percent of the mass is in drops above the MMD.

MEDIAN LETHAL CONCENTRATION (LC_{50})--stated concentration of active material in liquid formulation, dust mist, gas, or vapor resulting in death of half of the test subjects in a given time interval.

MEDIAN LETHAL DOSE (LD_{50})--the dose of insecticidal material (chemicals or microbials) producing death in half of the test subjects in a given time interval. A common method of expressing the toxicity of a compound. It is generally expressed as milligrams of a chemical per kilogram of body weight of the test animal (mg/kg). An LD_{50} is a statistical estimate of the dosage necessary to kill 50 percent of a very large population of the test species under stated conditions (e.g., single oral dose of aqueous solution), or by law, the dose which is expected to cause death within 14 days in 50 percent of the test animals treated. A compound with an LD_{50} of 10 mg/kg is more toxic than one with an LD_{50} of 100 mg/kg.

MESH (SCREEN)--standard screens are used to separate solid particles into size ranges. The mesh is stated in number of openings to each linear inch. The finest screen practical in this work is the 325 mesh which has openings 44 micrometers in diameter, 1 micrometer being equivalent to 0.001 mm. This screen has over 105,000 openings per square inch. Fine dusting sulfur preferably has 95 percent of the particles passing a 325-mesh screen. A common range for granular formulations is the 15-30 range. Particles small enough to pass a 60-mesh screen are considered dusts.

MICROMETER (μm)--a unit of length equal to one millionth of a meter.

mg--the abbreviation for milligram - 1/1000 of a gram.

mg/kg--used to express the amount of pesticide in milligrams per kilogram of animal body weight to produce a desired effect. 1 000 000 milligrams = 1 kilogram = 2.2 pounds.

NUMBER MEDIAN DIAMETER--the number median diameter is the diameter that divides all drops into two equal groups--50 percent of the drop sizes are above the NMD and 50 percent below.

OIL RED CARD--a red-dyed, oil-sensitive Kromekote® card which shows a white spot when an oil-base spray drop lands on the surface.

OIL SOLUTION--a pesticide chemical dissolved in oil.

OPERATIONAL CONTROL PROJECT--a project conducted to control a forest pest.

PERCENT CONCENTRATION--the weight or volume of a given compound expressed as a percentage of the final mixture.

PESTICIDE--a chemical or agent that will destroy a pest or protect something from a pest.

PILOT CONTROL PROJECT--tests involving materials and/or equipment to demonstrate and evaluate the operational aspects of the materials and/or equipment on a larger scale.

QUANTIMET®--an automatic spot and particle counting and image analyzing instrument manufactured by Cambridge Instrument Company, Inc.

RECOVERY RATE--amount of spray material which was accounted for or recovered on the deposit card, usually expressed as a percent of the amount disseminated.

RELATIVE HUMIDITY (RH)--the amount of moisture in the air compared with the total amount that the air could hold at that temperature.

RESEARCH TEST OR EXPERIMENT--field test conducted to evaluate a pesticide which showed promise in the laboratory.

SPECIFIC GRAVITY--density; the ratio of the mass (weight) of a material to the mass of an equal volume of water at a specified temperature, such as 20 ^{o}C.

SPECTRAL COUNTS--data reflecting number and size of droplet represented on a given sample.

SPRAY ACCOUNTABILITY--an accounting for the spray which has been released into the atmosphere, usually expressed in percent of original source.

SPRAY CLOUD--spray, consisting of aerosol or particulate-size particles or droplets, generated into the atmosphere from a spray device.

SPREAD FACTOR--an expression of the amount of spreading of an aerodynamic drop on a collecting surface. If a 50-micrometer aerodynamic drop makes a stain of 100 micrometers on a Kromekote® card, the spread factor will be 2.

SPREAD FACTOR EQUATION--a polynomial expression of the spread factor.

STAIN--the discoloration produced by the tank mix (drops of insecticide) on cards, foliage, or insects.

SUDAN BLACK CARDS--a purple card used to detect Malathion® drops. This card sometimes is called a Malathion sensitive card.

SWATH WIDTH--the area (span) in which the droplet density equals or exceeds a specified amount known or thought to produce the requisite pesticide effectiveness.

TANK MIX--the mixture resulting after the fomulation is diluted for field application.

TEMPERATURE GRADIENT (ΔT)--difference in temperature from the ground to a specified height expressed in ^{o}C. ΔT are usually described as lapse, neutral, or inversion. If the temperature warms with height, an inversion exists; if there is no difference in the temperature other than the adiabatic rate with height, a neutral exists; and if the temperature cools with height, a lapse exists.

VAPOR PRESSURE--the property which causes a chemical compound to evaporate; the lower the vapor pressure, the more volatile the compound.

NAMES AND ADDRESSES OF CONTRIBUTORS

Norman Akesson
Department of Agricultural Engineering
University of California, Davis
Davis, California 95616

John Barry
USFS FI&DM-Methods Application Group
2810 Chiles Road
Davis, California 95616

R. E. Cowden
Department of Agricultural Engineering
University of California, Davis
Davis, California 95616

R. K. Dumbauld
H. E. Cramer Co
P.O. Box 8049
Salt Lake City, Utah 84109

Robert Ekblad
USFS MEDC
Federal Building
Missoula, Montana 59801

Bohdan Maksymiuk
USFS Forestry Sciences Laboratory
3200 Jefferson Way
Corvallis, Oregon 97331

George Markin
USFS Pacific Southwest Forest and Range Experiment Station
Field Testing of Chemical Insecticides
2810 Chiles Road
Davis, California 95616

John Neisess
USFS Forestry Sciences Laboratory
3200 Jefferson Way
Corvallis, Oregon 97331

Richard Waite
USFS Forestry Sciences Laboratory
3200 Jefferson Way
Corvallis, Oregon 97331

Lynn Whyte
USFS FI&DM-Methods Application Group
2810 Chiles Road
Davis, California 95616

Robert Young
USFS FI&DM-Methods Application Group
2810 Chiles Road
Davis, California 95616

SPREAD FACTORS OF SELECTED INSECTICIDE TANK MIXES (Tables 4-6)

Richard Waite

Table 4--*Spread factor and linear relationship between spot (Y) and drop (X) diameter for microbial insecticides on Kromekote® cards*

Formulation	Dye[1/]	Mean spread factor	Range (spherical drop diameter µm)	Linear regression equation	Correlation coefficient
1/2 lb Dipel WP® in 25% CIB (Cargill Insecticide Base® -molasses) + H_2O to make 1 gal (filtered)	Rhod B S	1.82	80-400	Y=2.02X-34.37	0.9970
1 lb Dipel WP® in 25% CIB, + H_2O to make 1 gal (filtered)	Rhod B S	1.81	112-425	Y=2.22X-87.00	0.9900
1/2 lb Dipel WP® in 25% CIB, 3.2% Maywood formula, + H_2O to make 1 gal	BSF	2.42	86-387	Y=2.02X+77.26	0.9832
1/2 lb Dipel WP® in 25% CIB, 3.2% Maywood formula, 3% Chevron sticker, + H_2O to make 1 gal (decanted)	BSF	2.65	67-344	Y=2.35X+46.59	0.9873
50% Dipel LC® , 50% H_2O	Rhod B S	1.95	100-325	Y=1.93X+2.77	0.9808
67% Dipel LC® , 33% H_2O	Rhod B S	1.77	112-475	Y=2.35X-140.86	0.9749
1/2 lb Dipel WP® + 25% Sorbo® + H_2O to make 1 gal	Rhod B S	1.69	64-592	Y=1.83X-19.32	0.9950
1/2 lb Dipel WP® + 25% Sorbo® + 5% wt/vol Shade + H_2O to make 1 gal	Rhod B S	1.56	64-688	Y=2.00X-81.12	0.9897
1 lb Dipel WP® in 12.5% Biofilm® , + H_2O to make 1 gal	BSF	2.79	86-344	Y=2.69X+23.21	0.9762
1 lb Dipel®, 0.125% Biofilm®	Rhod B S	1.74	75-550	Y=2.04X-48.70	[2/] 0.9973
25% Thuricide HPC® , 25% CIB, 3% sticker, and 47% H_2O	BSF	2.24	92-516	Y=2.40X-31.45	0.9560
	BSF	2.06	92-516	Y=2.29X-42.78	[3/] 0.9590
50% Thuricide 16B®, 50% H_2O	Rhod B S	1.88	87-525	Y=1.87X+1.30	0.9976
25% Thuricide 16B®, 75% H_2O	Rhod B S	1.94	100-300	Y=1.91X+5.45	0.9951
50% Thuricide 16B®, 0.2% wt/vol $FeCl_3$ + H_2O to make 1 gal	No dye	2.13	97-548	Y=2.04X+16.24	0.9816
33% Thuricide 24B®, 67% H_2O	Rhod B S	2.17	86-387	Y=2.32X-28.58	0.9910
25% Thuricide 32B®, 50% H_2O, 25% Sorbo®	Rhod B S	1.64	86-333	Y=1.80X-24.69	0.9944
50% Sandoz V® [4/] with Shade, 50% H_2O	No dye	1.62	129-280	Y=1.87X-46.85	0.9652
25% CIB, 75% H_2O [5/]	BSF	1.99	43-430	Y=1.57X+61.85	0.9848
25% CIB, 0.5 lb/gal Shade + H_2O to make 1 gal [5/]	BSF	1.94	70-323	Y=2.00X-10.15	0.9769

[1/] Rhod B S is Rhodamine B extra S and BSF is Brilliant Sulpho Flavine FFA.

[2/] Printflex cards.

[3/] Kromekote® cards with glossy coat on one side.

[4/] An aerial adjunct for virus formulation from Sandoz Co.

[5/] Carrier for nucleopolyhedra virus (NPV) formulation for Douglas-fir tussock moth.

Table 5--*Spread factor and linear relationship between spot (Y) and drop (X) diameter for chemical insecticides on Kromekote® cards*

Formulation	Dye	Mean spread factor	Range (spherical drop diameter μm)	Linear regression equation	Correlation coefficient
Oil base:					
0.01 lb/gal Bioethanomethrin, 1% Wingstay 100® 2/ Goodrich in Klearol to make 1 gal	Rhod B 1/	4.30	86-344	Y=4.57X-46.38	0.9789
0.01 lb/gal Bioethanomethrin, 1% Wingstay 100® 2/ Goodrich in Panasol® to make 1 gal	Rhod B	5.70	86-237	Y=6.06X-51.34	0.9519
0.1 lb/gal Pyrethrins, 5.6% Dowanol DB®, 89.2% heavy mineral oil, 3.6% stabilizers	Oil red 0	6.06	129-430	Y=6.74X-139.82	0.9994
	Oil red 0	5.64	129-430	Y=6.53X-183.20	3/ 0.9956
67% Dylox 1.5®, 33% Orchex 796®	Rhod B	2.20	129-688	Y=2.13X+9.66	0.9948
Dylox 1.5® oil undiluted	Rhod B	2.31	64-344	Y=1.91X+70.48	0.9847
Dylox 4® undiluted	Rhod B	3.91	108-688	Y=4.15X-37.52	0.9976
Fuel oil No. 2	Rhod B	4.82	43-258	Y=5.26X-42.77	0.9923
Sevin 4-oil® undiluted	Rhod B	2.18	70-194	Y=2.07X+17.24	0.9742
25% Sevin 4-oil®, 75% No. 2 fuel oil	Rhod B	4.09	76-344	Y=4.30X-42.56	0.9941
67% Sevin 4-oil®, 33% No. 2 fuel oil	No dye	2.13	129-297	Y=2.47X-63.60	0.9519
	No dye	2.12	129-297	Y=2.37X-47.67	4/ 0.9526
	No dye	2.38	129-297	Y=2.40X-4.05	5/ 0.9513
50% Sevin 4-oil®, 50% No. 2 fuel oil	Rhod B	2.31	86-443	Y=2.40X-20.59	0.9945
10% Sumithion®, 20% Panasol®, 70% No. 2 fuel oil	Rhod B	4.32	86-312	Y=5.60X-235.78	0.9915
Dowanol TPM® (carrier for Zectran®)	Sudan Deep Black	4.93	43-301	Y=5.46X-60.74	3/ 0.9905
Dowanol TPM®, (carrier for Zectran®)	No dye	7.69	65-387	Y=9.45X-202.49	4/ 0.9944
10% Zectran FS 1.5®, 90% No. 2 fuel oil	Rhod B	4.87	65-473	Y=5.60X-107.71	0.9901
	Rhod B	4.86	65-473	Y=4.90X-70.58	3/ 0.9893
10% Zectran FS 1.5®, 90% Chevron C	Rhod B	3.99	75-430	Y=4.86X-123.12	3/ 0.9957
Water base:					
0.25 lb Dimilin 25% WP® + H_2O to make 1 gal	Nigrosine	1.99	194-441	Y=1.89X+30.99	0.9737
0.5 lb Dimilin 25% WP® + H_2O to make 1 gal	Nigrosine	1.81	129-473	Y=1.70X+29.84	0.9865
1 lb Dimilin 25% WP® + H_2O to make 1 gal	Nigrosine	2.14	86-602	Y=2.32X-44.24	0.9971
1 lb Dimilin 25% WP®, 10% ethylene glycol, in H_2O to make 1 gal	Rhod B S	2.18	86-430	Y=2.28X-16.46	0.9971
Imidan IE® undiluted	Rhod B	4.57	129-322	Y=4.77X-23.79	0.9991
75% Imidan IE®, 25% H_2O	Rhod B	3.97	97-473	Y=5.15X-204.72	0.9995
50% Imidan IE®, 50% H_2O	Rhod B	4.90	86-280	Y=4.37X+95.37	0.9918
1 lb Orthene 75SP® in H_2O to make 1 gal	Nigrosine	2.18	43-494	Y=2.41X-49.44	0.9880
1 lb Orthene 75SP®, 10% ethylene glycol in H_2O to make 1 gal	Rhod B S	1.75	86-860	Y=1.89X-38.09	0.9992
1 lb Orthene 75SP®, 0.1% wt/vol $FeCl_3$ in H_2O to make 1 gal	No dye	2.06	86-387	Y=2.22X-33.39	0.9788

1/ Rhod B is Rhodamine B extra base.
2/ Manufactured by B. F. Goodrich Co.
3/ Kromekote® cards with glossy coat on one side.
4/ Red-dyed Kromekote® cards.
5/ Blue-dyed Kromekote® cards.

Table 6--*Spread factor and linear relationship between spot (Y) and drop (X) diameter for water, herbicides and fertilizers on Kromekote® cards*

Formulation	Dye[1/]	Mean spread factor	Range (spherical drop diameter µm)	Linear regression equation	Correlation coefficient
Water:					
Distilled water + detergent	0.1% Nigrosine	2.77	75-344	Y=2.89X-18.17	0.9779
Distilled water	0.1% BSF	1.85	32-387	Y=1.76X+10.91	0.9958
Distilled water	0.1% Rhod B S	1.72	75-602	Y=1.81X-19.32	0.9951
Distilled water	0.1% Nigrosine	1.63	100-500	Y=1.90X-57.99	0.9896
Distilled water	0.5% Nigrosine	1.82	129-430	Y=1.64X+38.72	0.9715
Distilled water	0.5% Calcofluor	2.18	118-366	Y=1.85X+67.14	0.9324
Herbicides and fertilizers:					
1 723.0 g nitrogen, + H_2O to make 1 liter	Nigrosine	2.71	65-409	Y=2.93X-31.35	0.9866
422.6 g nitrogen, + H_2O to make 1 liter	Nigrosine	2.76	129-705	Y=2.67X+27.17	0.9900
16.3 g 2,4,5-T, + H_2O to make 1 liter	Nigrosine	2.86	27-2000	Y=3.08X-37.78	0.9993
2 lb Benlate, + H_2O to make 1 gal	Rhod B S	2.42	108-731	Y=2.70X-92.45	0.9949

[1/] BSF is Brilliant Sulpho Flavine FFA and Rhod B S is Rhodamine B extra S.

SPREAD FACTORS OF SELECTED INSECTICIDE TANK MIXES*

Table 7--*Spread factors of insecticide tank mixes*

Tank mixes	Dye	Collection material	Specific mixture
1. Malathion® technical (95%1/ Cythion® Tech.)	None	Sudan Black® cards	100% Malathion® as received
2. Sevin 4-Oil®: 80% Sevin 4-Oil® and 20% No. 2 fuel oil	None	Black construction paper	400 ml Sevin 4-oil® 100 ml No. 2 fuel oil
3. Sevin 4-oil®: 80% Sevin 4-oil® and 18% No. 2 fuel oil	Automate Red 2%	White Kromekote® cards	400 ml Sevin 4-oil® 90 ml No. 2 fuel oil 10 ml Automate Red
4. Sevin 4-oil®: 4 parts plus 1 part diesel fuel by volume	No dye	Black construction paper and Sudan Black cards	400 ml Sevin 4-oil® 100 ml diesel fuel
5. Dylox 4®, 50%: HI SOL® 4-5-T 48%	Automate Red 2%	White Kromekote® cards	500 ml Dylox 4® 480 ml HI SOL® 4-5-T 20 ml Automate Red
6. Dylox 4®, 24 oz; HI SOL® 8 oz	Automate Red 2%	White Kromekote® cards	709.8 ml Dylox 4® 236.6 ml HI SOL® 19.3 ml Automate Red
7. Orthene 75S®, 1.33 lb and enough water to make 1 gal of total material	Rhodamine B 0.15% by weight	White Kromekote® cards	301.9 g Orthene 75S® diluted to 1.893 liter water 2.9 g Rhodamine B
8. Herbicide 2,4-D water mixture	Rhodamine B 0.15% by weight	White Kromekote® cards	103.4 ml 2,4-D 896.4 gal water 1.5 g Rhodamine B

1/ % indicates volumetric ratios.

* Provided by Fame Associates, Fort Collins, Colorado, through contract with USDA Forest Service, Equipment Development Center, Missoula, Montana, for USDA Forest Service, Forest Insect and Disease Management Methods Application Group, Davis, Calif.

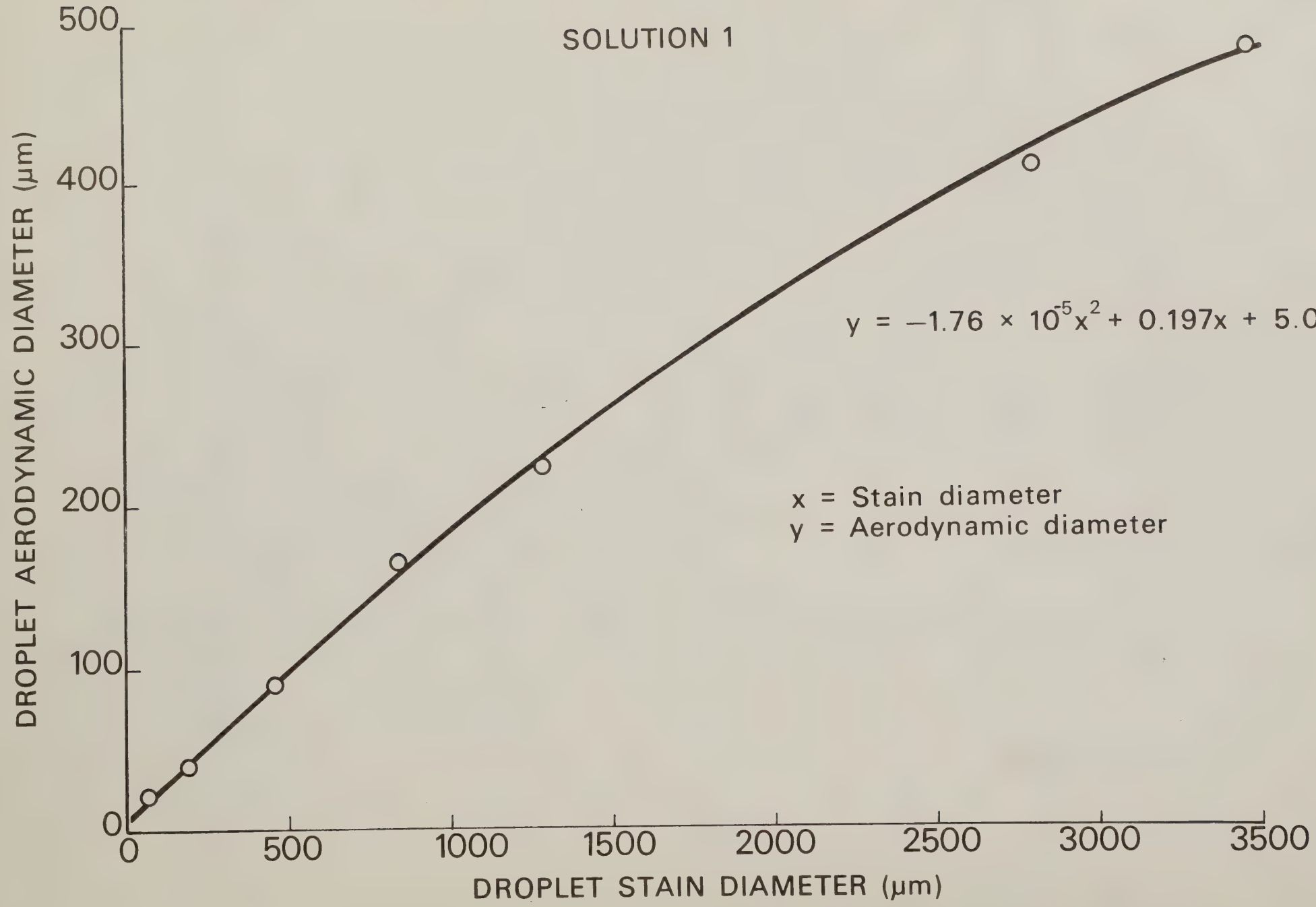

Figure 31.--Spread factor equation for Malathion® Technical (95 percent Cythion Technical) on Sudan Black cards.

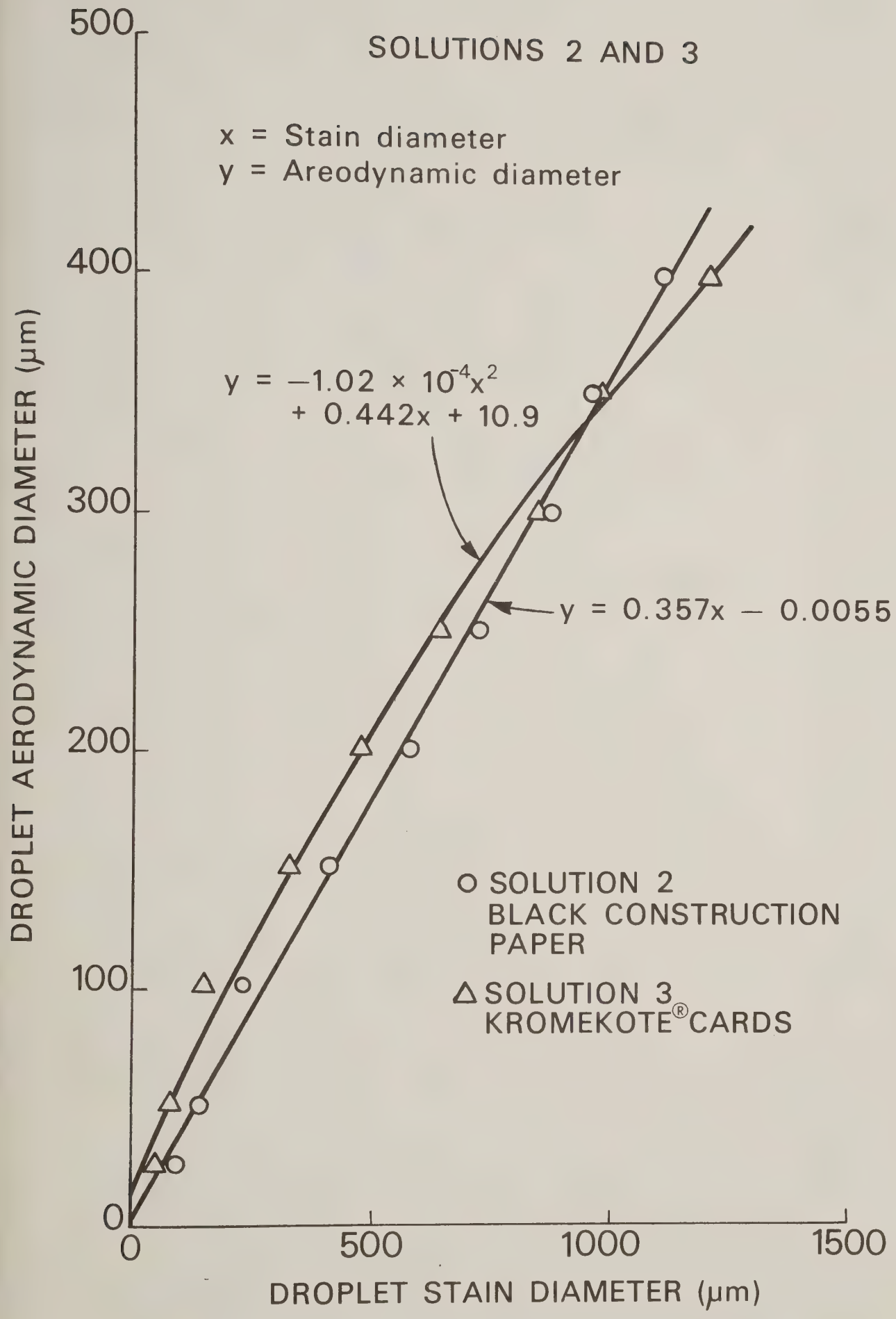

Figure 32.--Spread factor equation for Sevin 4-oil® on black construction paper and white Kromekote® cards.

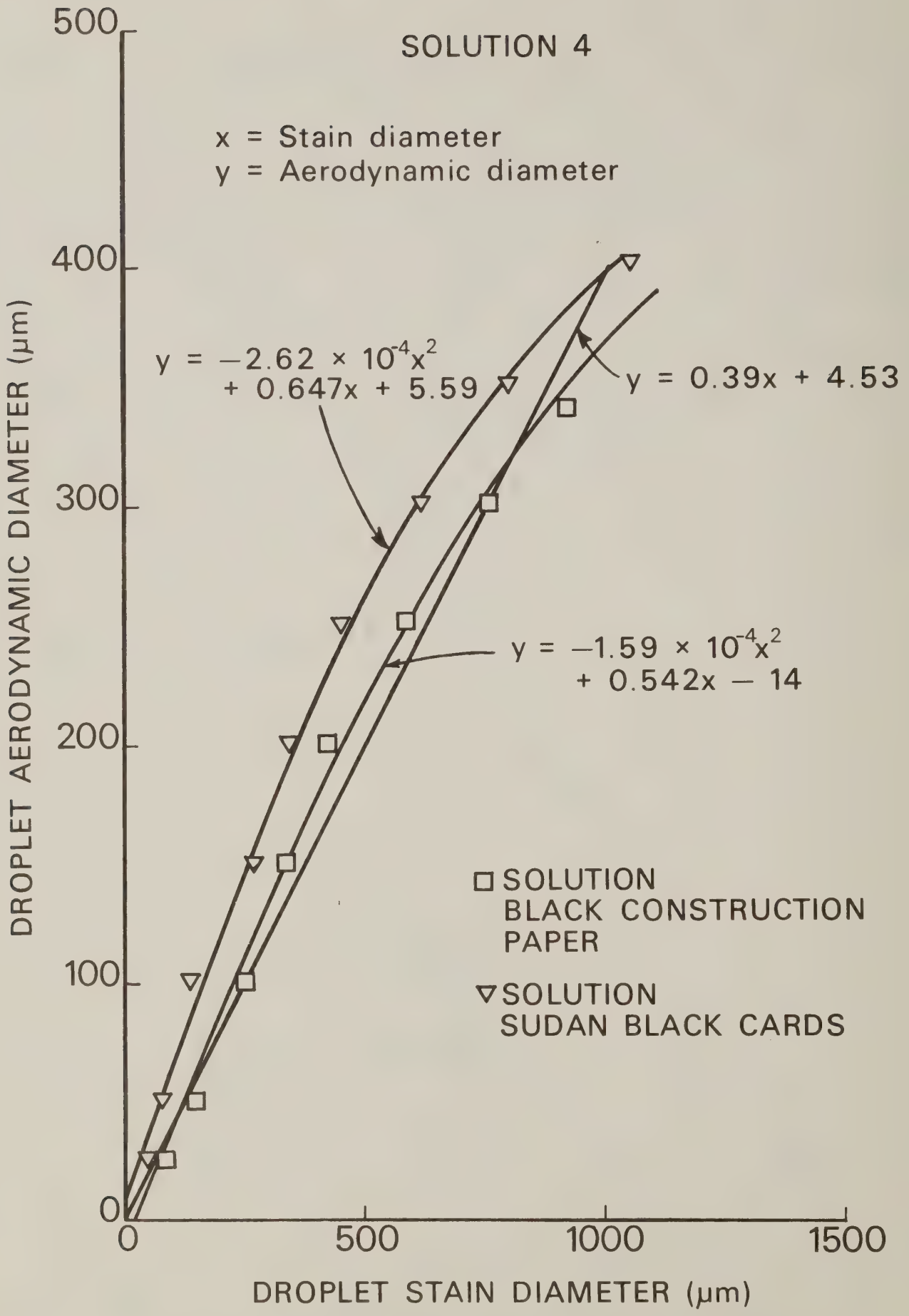

Figure 33.--Spread factor equation for Sevin 4-oil® on black construction paper and Sudan Black cards.

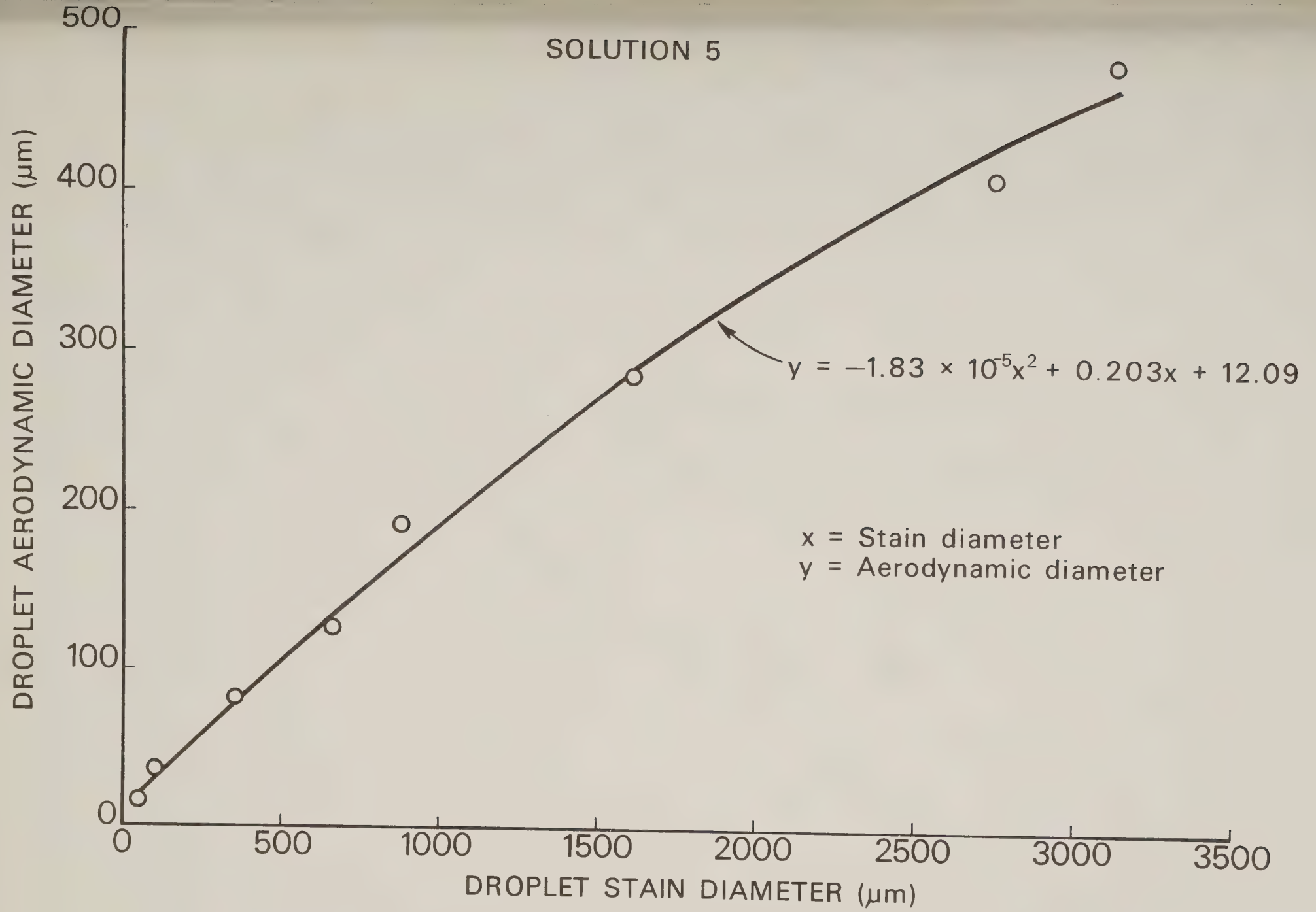

Figure 34.--Spread factor equation for Dylox 4®, 50 percent and HI SOL® 4-5-T, 48 percent on white Kromekote® cards.

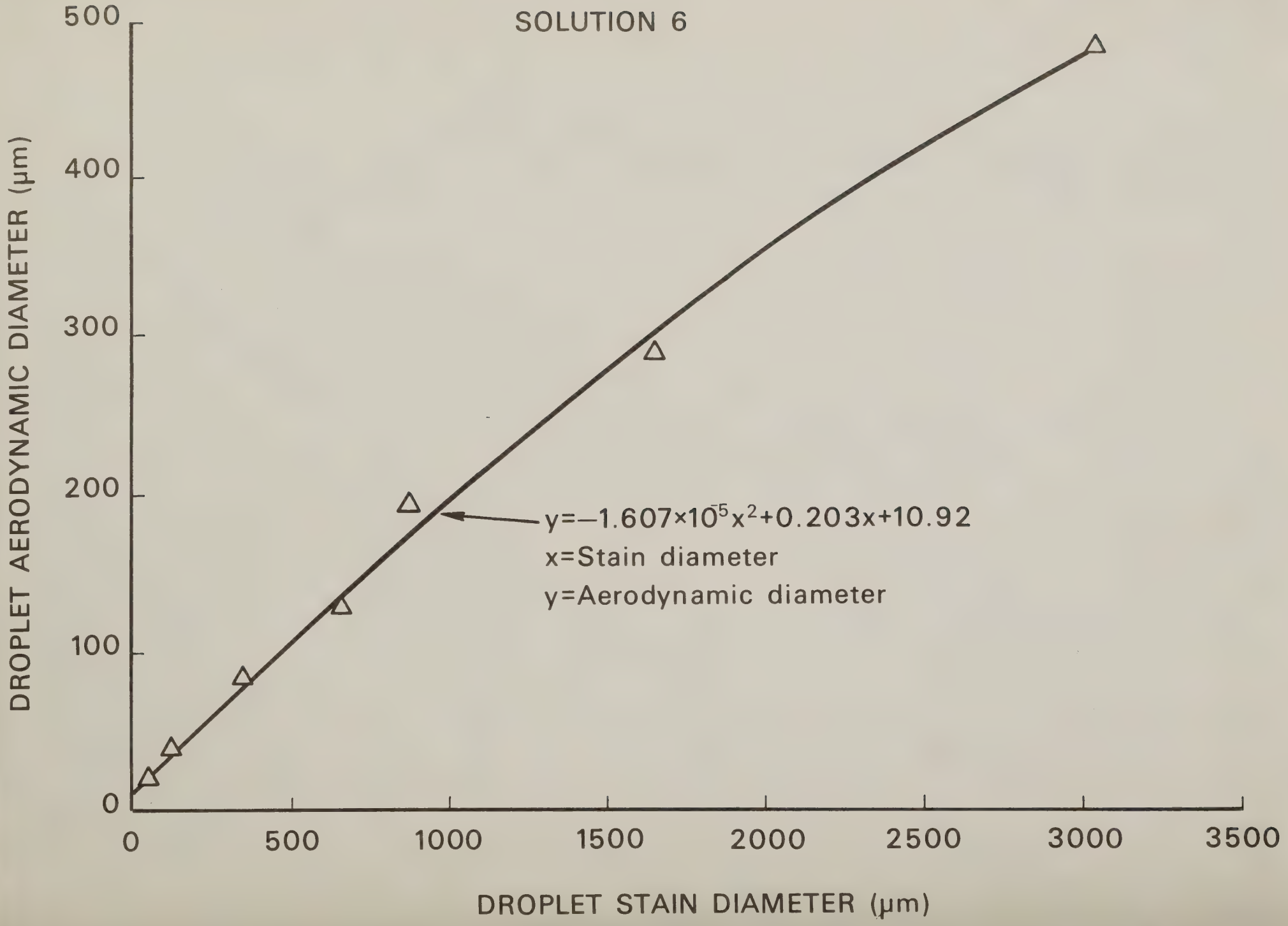

Figure 35.--Spread factor equation for Dylox 4®, 24 oz and HI SOL®, 8 oz on white Kromekote® cards.

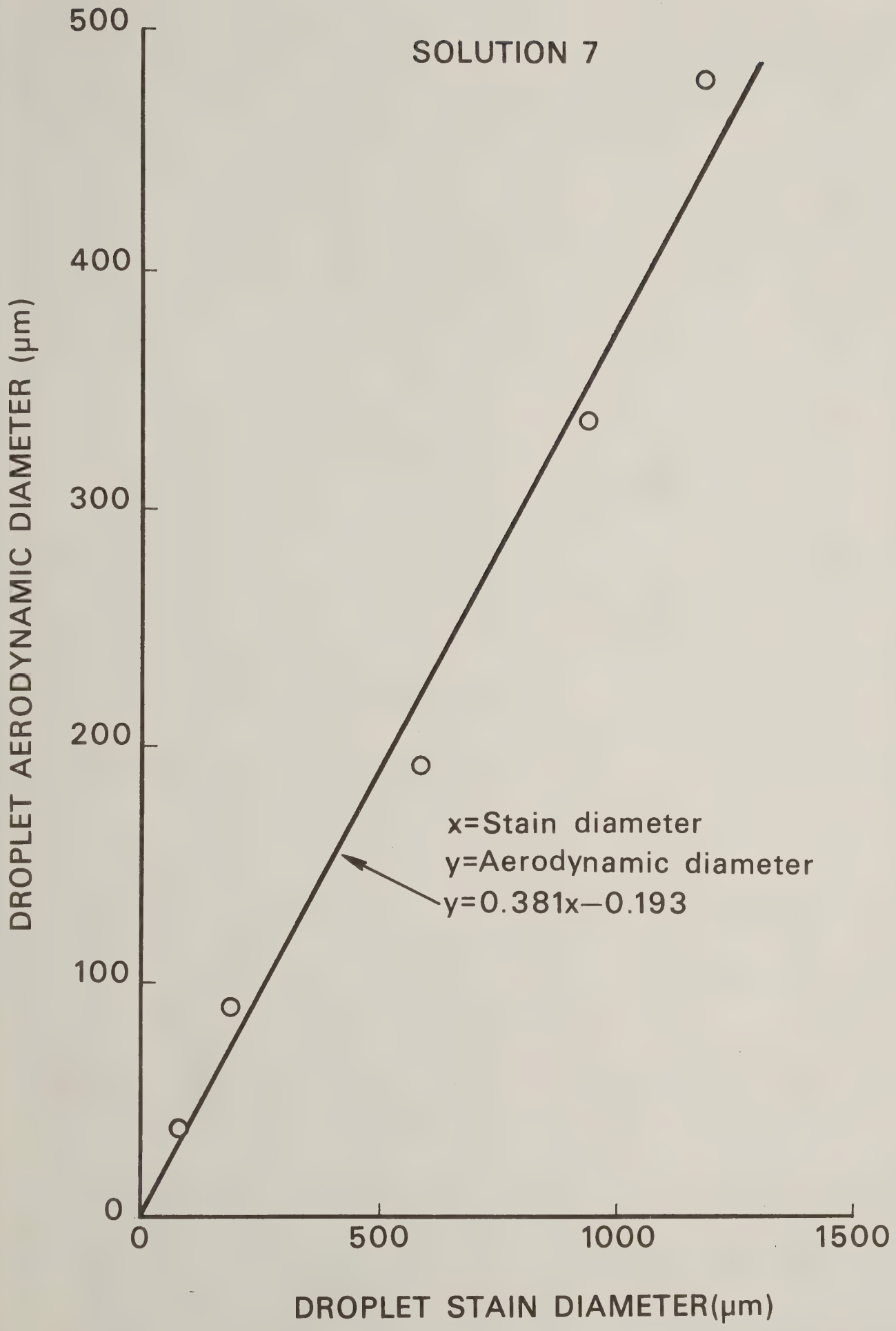

Figure 36.--Spread factor equation for 1.33 lb Orthene 75S® in 1 gal water on white Kromekote® cards.

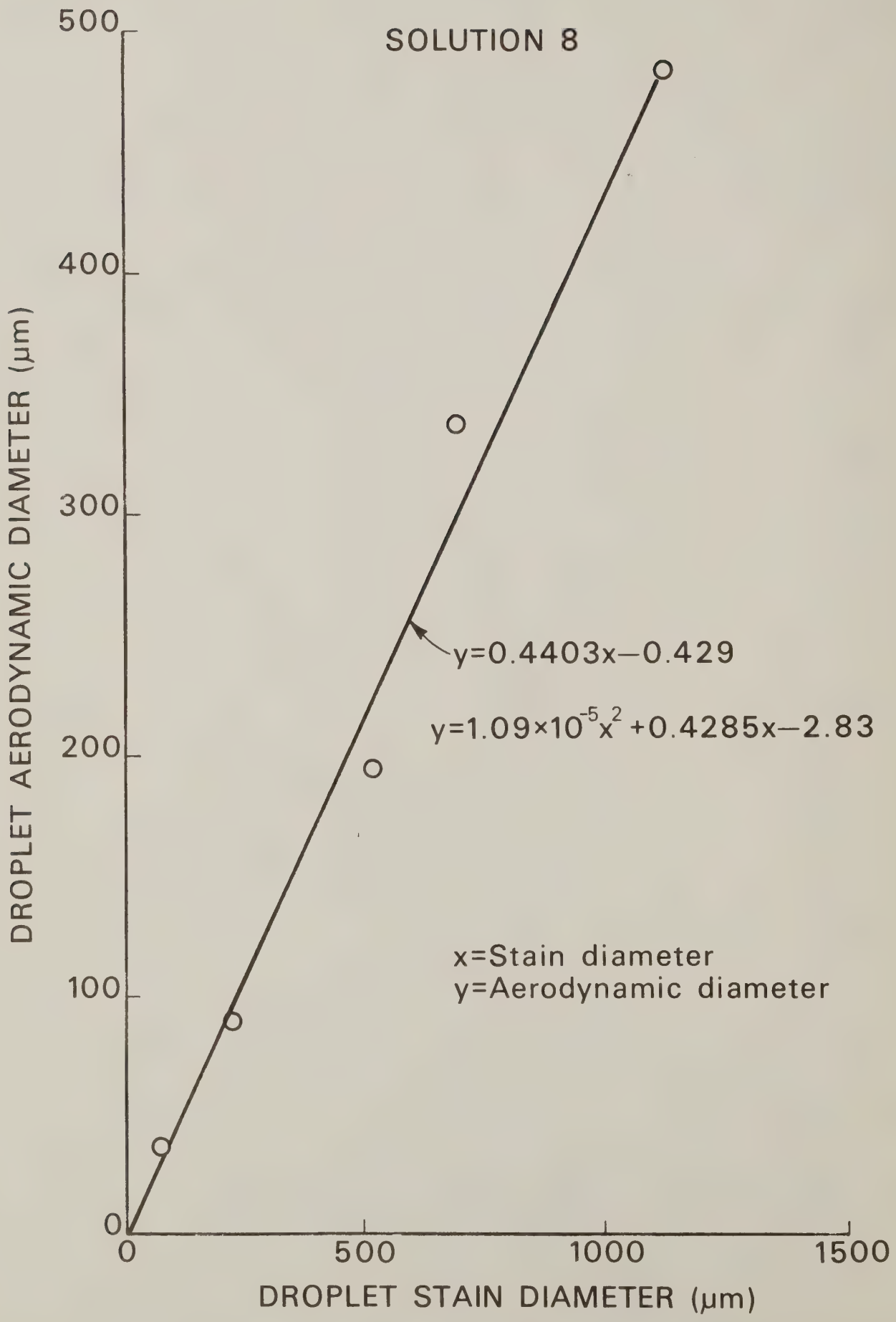

Figure 37.--Spread factor equation for one-half pound Orthene 75S® in one-half gallon of water on white Kromekote® cards.

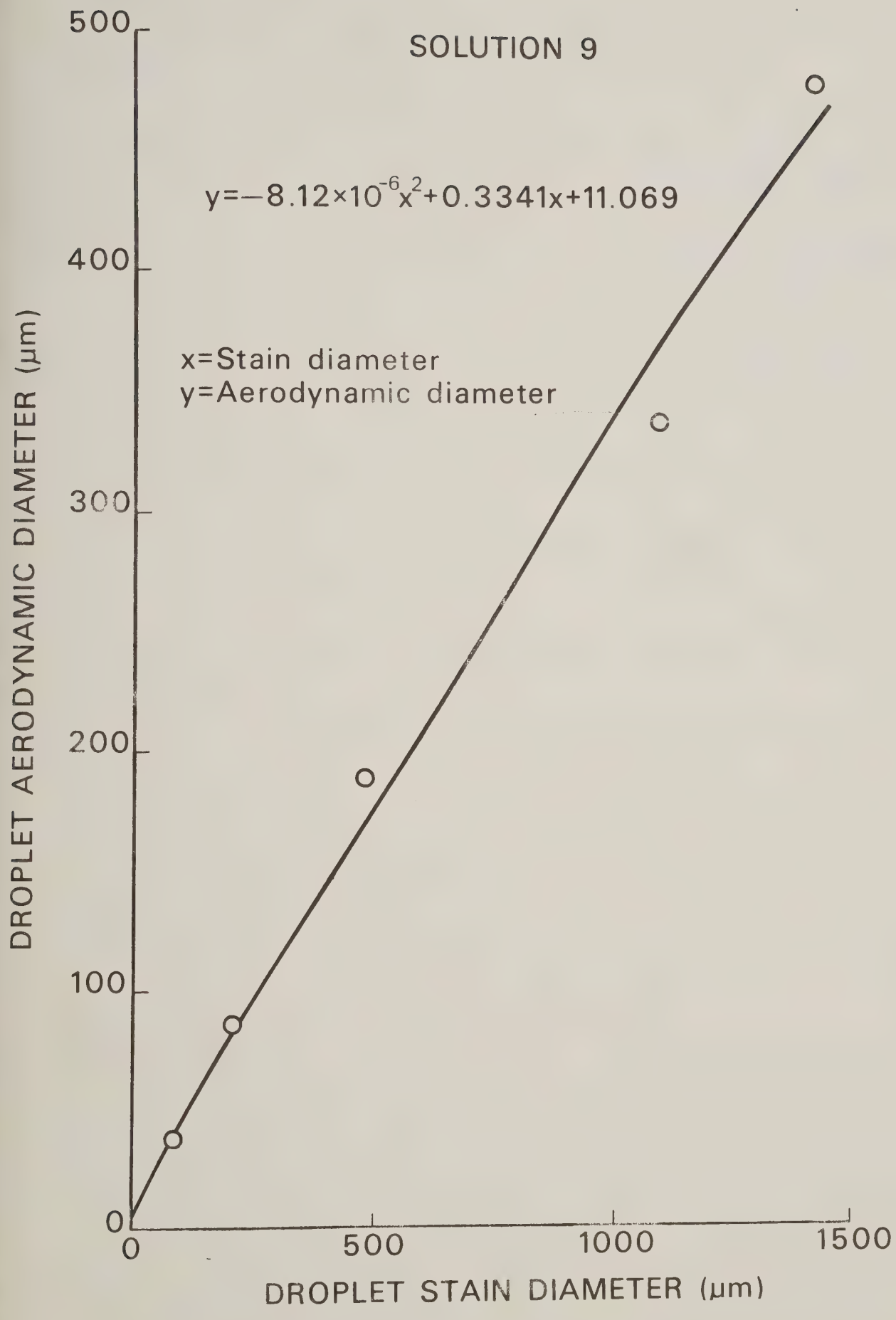

Figure 38.--Spread factor equation for herbicide 2,4-D water mixture on white Kromekote® cards.

SOURCES OF MATERIALS

Kromekote® cards:

Industrial Chemicals Corporation
4711 West 58th Avenue
Arvada, Colorado 80002

The Mead Corporation
Dayton, Ohio 45402

Home and Farm Chemical Co.
P.O. Box 6055
Charlotte, North Carolina 28207

Quantimet® analysis:

Energy Research and Development Administration
Albuquerque Operation Office
P.O. Box 5400
Albuquerque, New Mexico 87115
(Analysis completed at Los Alamos Scientific Lab)

University of California
Davis Campus
Department of Advanced Instrumentation
Davis, California 95616

Kromekote® cardholder specifications:

MEDC
Federal Building
Missoula, Montana 59801

Sudan black and oil red cards:

Home and Farm Chemical Co.
Post Office Box 6055
Charlotte, North Carolina 28207

Fire weather instrument kit--belt type complete:

Western Fire Equipment Co.
440 Valley Drive
Brisbane, California 94005

Kromekote® cardholders:

General Binding Corporation
169 South Stevens
Spokane, Washington 99204

SOURCES OF DYES AND TRACERS

Chemical	Cost*	Source
Automate Red	$3.05/lb 40 lb container	Morton Chemical Co. 110 N. Walker Drive Chicago, Illinois
Rhodamine B Extra S	$7.60/lb 30 lb container	GAF Corporation Chemical & Dyestuff Division 525 East Imperial Highway Harbor, California 90613
Rhodamine B Extra B	$8.90/lb 50 lb container	GAF Corporation Chemical & Dyestuff Division 525 East Imperial Highway Harbor, California 90613
Calcofluor	$1.13/lb 42 lb container	American Cyanamid Company Dyes Department 3145 N.W. Yeon Portland, Oregon 97210
Oleic acid	$5.50/gal	ICN Pharmaceuticals, Inc. Life Sciences Group 26201 Miles Road Cleveland, Ohio 44128
Nigrosine	$1.82/lb 10 lb quantity	GAF Corporation Chemical & Dyestuff Division 525 East Imperial Highway Harbor, California 90613
Ferric chloride	$7.60/lb 12 lb quantity	MCB Manufacturing Chemists 2909 Highland Avenue Norwood, Ohio 45212
Oil red dye	$4.29/lb 100 lb quantity	E. I. DuPont Company 111 Sutter Street Room 834 San Francisco, Calif. 94104
Tinopal SFG		CIBA-GIEGY Dyestuff Chemical Div. Hook Road Bayonne, New Jersey

* As of date of publication.

SOURCES FOR DETERMINING SPREAD FACTORS

Los Alamos Scientific Laboratory
CMB-11
P.O. Box 1663
Los Alamos, New Mexico 87544
Attention: Kaye Johnson

University of Georgia
Department of Entomology
Athens, Georgia 30602
Attention: Chet Himel

Fame Associates
P.O. Box 572
Fort Collins, Colorado 80522
Attention: James Wedding

University of California
Department of Agriculture Engineering
Davis Campus
Davis, California 95616
Attention: Robert Stormont

U.S. Forest Service
Forestry Sciences Laboratory
3200 Jefferson Way
Corvallis, Oregon 97331
Attention: Richard Waite

CONVERSION TABLES

COMMON EQUIVALENTS AND CONVERSION FACTORS[1/]

Approximate Common Equivalents		Conversions Accurate to Parts/Million	
1 inch	= 25 millimeters	inches x 25.4*	= millimeters
1 foot	= 0.3 meter	feet x 0.3048*	= meters
1 yard	= 0.9 meter	yards x 0.9144*	= meters
1 mile	= 1.6 kilometers	miles x 1.609 34	= kilometer
1 sq. inch	= 6.5 sq. centimeters	sq. in. x 6.4516*	= sq. centimeters
1 sq. foot	= 0.09 sq. meter	sq. ft. x 0.092 903	= sq. meters
1 sq. yard	= 0.8 sq. meter	sq. yards x 0.836 127	= sq. meters
1 acre	= 0.4 hectare	acres x 0.404 686	= hectares
1 cu. inch	= 16 cu. centimeters	cu. inches x 16.3871	= cu. centimeters
1 cu. foot	= 0.03 cu. meter	cu. feet x 0.028 316	= cu. meters
1 cu. yard	= 0.8 cu. meter	cu. yards x 0.764 555	= cu. meters
1 quart	= 1 liter	quarts (lg) x 0.946 353	= liters
1 gallon	= 0.004 cu. meter	gallons x 0.003 785 41	= cu. meter
1 ounce (avdp)	= 28 grams	ounces (avdp) x 28.3495	= grams
1 pound (avdp)	= 0.45 kilogram	pounds (avdp) x 0.453 592	= kilograms
1 millimeter	= 0.04 inch	millimeters x 0.039 370 1	= inches
1 meter	= 3.3 feet	meters x 3.280 84	= feet
1 meter	= 1.1 yards	meters x 1.093 61	= yards
1 kilometer	= 0.6 mile	kilometer x 0.621 371	= miles
1 sq. centimeter	= 0.16 sq. in.	sq. centimeter x 0.155 000	= sq. in.
1 sq. meter	= 11 sq. feet	sq. meters x 10.7639	= sq. feet
1 sq. meter	= 1.2 sq. yards	sq. meters x 1.195 99	= sq. yards
1 hectare	= 2.5 acres	hectares x 2.471 05	= acres
1 cu. centimeter	= 0.06 cu. in.	cu. centimeters x 0.061 027 7	= cu. in.
1 cu. meter	= 1.3 cu. yards	cu. meter x 1.307 95	= cu. yards
1 cu. meter	= 35 cu. feet	cu. meters x 35.3147	= cu. feet
1 liter	= 1 quart	liters x 1.056 69	= quarts
1 cu. meter	= 250 gallons	cu. meters x 264.172	= gallons
1 gram	= 0.035 ounces	grams x 0.035 274 0	= ounces
1 kilogram	= 2.2 pounds	kilograms x 2.204 62	= pounds
1 ton	= 1.016 047 0 metric tons or 1,016.0470 kilograms		

* Exact.

1/ The Modernized Metric System. Special Publication 304A. U.S. Department of Commerce, National Bureau of Standards. Revised 1970.

[Source: Neal (1974, table 25, p. 61, used with permission).]

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[Table 8]

TABLE 23. Weight conversion units[1/]

Units to be converted	Multiply by figures below				
	Grains	Grams	Ounces	Pounds	Kilograms
Grains	1	0.0647	0.0022	0.00014	0.00006
Grams	15.432	1	0.035	0.0022	0.001
Ounces	437.50	28.34	1	0.0625	0.0283
Pounds	7,000.0	453.59	16	1	0.453
Kilograms	15,432.3	1000.0	35.273	2.204	1

[Source: Neal (1974, used with permission).]

[Table 9]

TABLE 24. Liquid capacity conversion units

Units to be converted	Multiply by figures below					
	Ounces, fluid	Pints	Quarts	Gallons	Milli-liters	Liters
Ounces, fl.	1.0	0.0625	0.031	0.0078	29.572	0.0295
Pints	16.0	1.0	0.5	0.125	473.167	0.4731
Quarts	32.0	2.0	1.0	0.25	946.33	0.946
Gallons	128.0	8.0	4.0	1.0	3,785.33	3.785
Milliliters	0.0338	0.0021	0.0010	0.0002	1.0	0.0010
Liters	33.814	2.113	1.056	0.264	1000	1.0

[1/] All weights are avoirdupois as opposed to troy weight for gold, silver, other precious metals, stones, and drugs.

[Source: Neal (1974, used with permission).]

[Table 10]

TABLE 17.--Dimensions of some fractions of an acre and a hectare expressed in square feet.

Fractions	Area in square feet		Dimensions of area in a square plot	
	Acre	Hectare	Acre	Hectare
1.0	43,560.00	107,636.76	208.71[1/]	328.08
1/2	21,780.00	53,818.38	147.58	321.98
1/3	14,520.00	35,878.92	120.49	189.41
1/4	10,890.00	26,909.19	104.35	164.04
1/5	8,712.00	21,527.35	93.33	146.72
1/8	5,445.00	13,454.59	73.79	115.99
1/10	4,356.00	10,763.67	66.00	103.74
1/12	3,630.00	8,969.73	60.24	94.70
1/15	2,904.00	7,175.78	53.88	84.70
1/20	2,178.00	5,381.83	46.66	73.36
1/25	1,742.40	4,305.47	41.74	65.61
1/30	1,452.00	3,587.89	38.10	59.89
1/40	1,089.00	2,690.91	33.00	51.87
1/50	871.20	2,152.73	29.51	46.39
1/75	580.80	1,435.15	24.09	37.88
1/100	435.60	1,076.36	20.87	32.80
1/200	217.80	538.18	14.75	23.19
1/400	108.90	269.09	10.43	16.40
1/800	54.45	134.54	7.37	11.59
1/1000	43.56	107.63	6.6	10.37

[1/] 208.71 x 208.71 = 43,560 or 1 acre.

[Source: Neal (1974, used with permission).]

[Table 11]

TABLE 18. Table of equivalents, percent to milligrams/liter, ppm, grams/liter, milligrams/milliliter, and micrograms/microliter

Percent	mg/liter ppm	g/liter mg/ml µg/µl	Percent	mg/liter ppm	g/liter mg/ml µg/µl
10.00	100,000	100. 1/	0.04	400.	.40
9.0	90,000	90.	0.0333	333.	.333
8.0	80,000	80.	0.030	300.	.300
7.5	75,000	75.	0.025	250.	.250
7.0	70,000	70.	0.020	200.	.200
6.0	60,000	60.	0.0167	167.	.167
5.0	50,000	50.	0.0150	150.	.150
4.0	40,000	40.	0.0143	143.	.143
3.0	30,000	30.	0.0125	125.	.125
2.5	25,000	25.	0.0111	111.	.111
2.0	20,000	20.	0.010	100.	.10
1.0	10,000	10.0	0.007	75.	.075
0.8	8,000	8.0	0.005	50.	.050
0.5	5,000	5.0	0.002	25.	.025
0.4	4,000	4.0	0.00125	12.5	.0125
0.25	2,500	2.5	0.00100	10.00	.0100
0.2	2,000	2.0	0.000625	6.25	.0062
0.1	1,000	1.0 2/	0.00031	3.12	.0031
0.08	800	.80	0.000156	1.56	.0015
0.0667	667	.67	0.00010	1.00	.0010
0.06	600	.60	0.00008	0.78	.00078
0.05	500	.50	0.00005	0.50	.00050

1/ 100 g/liter (50 g/500 ml)

2/ 1 g/liter (.5 g/500 ml)

[Source: Neal (1974, used with permission).]

TABLE 19. Gallons of concentrate required in 100 gal or less of water per area[1/]

Concentrate (lb AI/gal)	Dosage rate: Pounds active ingredients in 100 gal[2/]							
	3.0	2.5	2.0	1.5	1.0	0.75	0.50	0.25
	Gallons							
1.0	3.00	2.50	2.00	1.50	1.00	0.750	0.500	0.250
1.5	2.00	1.67	1.33	1.00	0.66	0.500	0.333	0.166
2.0	1.50	1.25	1.00	0.75	0.50	0.375	0.250	0.125
2.5	1.20	1.00	0.80	0.60	0.40	0.300	0.200	0.100
3.0	1.00	0.83	0.67	0.50[3/]	0.33	0.250	0.166	0.083
3.2	0.94	0.78	0.62	0.47	0.31	0.234	0.156	0.078
3.3	0.91	0.75	0.60	0.45	0.30	0.227	0.151	0.075
3.5	0.86	0.71	0.57	0.43	0.28	0.214	0.142	0.071
4.0	0.75	0.62	0.50	0.37	0.25	0.187	0.125	0.062
4.5	0.67	0.55	0.44	0.33	0.22	0.166	0.111	0.055
5.0	0.60	0.50	0.40	0.30	0.20	0.150	0.100	0.050
5.5	0.54	0.45	0.36	0.27	0.18	0.136	0.090	0.045
6.0	0.50	0.42	0.33	0.25	0.16	0.125	0.083	0.041
8.0	0.37	0.31	0.25	0.19	0.12	0.093	0.062	0.031

[1/] For 99 gal or less, multiply the number of gallons of spray needed times the value in Table 19. Thus, 50 gal of spray solution at 1 lb AI with 2 lb AI/gal would be 0.25 gal (50 gal x 0.50 = 0.25).

[2/] To obtain amounts not given in table use the following method: Divide number of pounds recommended rate by the number of pounds AI/gallon. Thus, 1 lb/area from 2 lb AI/gal is 0.50 gal formulation.

[3/] For milliliter equivalent refer to Table 3 [table 3 not reproduced in this publication]. Move decimal two places to the right for correct number of milliliters. Thus, the milliliter equivalent to 0.50 gal above is 1,893.

[Source: Neal (1974, used with permission).]

TABLE 26. Dry weight conversions, kilograms per hectare to pounds per acre, pounds per hectare, and kilograms per acre

Kilograms per hectare	Pounds per acre	Pounds per hectare	Kilograms per acre
.1	.09	.2205	.0405
.25	.22	.5512	.1012
.50	.45	1.1023	.2023
.75	.67	1.6535	.3035
1.0	.89	2.2046	.405
2.0	1.8	4.4092	.809
3.0	2.7	6.6138	1.214
4.0	3.6	8.8184	1.619
5.0	4.5	11.0230	2.023
6.0	5.3	13.2276	2.428
7.0	6.2	15.4322	2.833
8.0	7.1	17.6368	3.238
9.0	8.0	19.8414	3.642
10.0	8.9	22.0460	4.047
15.0	12.5	33.0690	6.070
20.0	17.8	44.0920	8.093
30.0	26.8	66.1380	12.140
40.0	35.7	88.1840	16.187
50.0	44.6	110.2300	20.234
60.0	53.5	132.2760	24.281
70.0	62.5	154.3220	28.328
80.0	71.4	176.3680	32.375
90.0	80.3	198.4140	36.422
100.0	89.2	220.4600	40.4687

[Source: Neal (1974, used with permission).]

TABLE 27. Dry weight conversions, pounds per acre to kilograms per hectare, pounds per hectare, and kilograms per acre

Pounds per acre	Kilograms per hectare	Pounds per hectare	Kilograms per acre
.1	.112	.25	.045
.25	.280	.62	.114
.50	.560	1.23	.227
.75	.841	1.85	.341
1.0	1.1209	2.47	.454
2.0	2.2417	4.94	.907
3.0	3.3626	7.31	1.361
4.0	4.4834	9.88	1.814
5.0	5.6043	12.35	2.268
6.0	6.7251	14.83	2.722
7.0	7.8460	17.30	3.175
8.0	8.9669	19.72	3.629
9.0	10.8077	22.24	4.082
10.0	11.2086	24.71	4.536
15.0	16.2129	37.07	6.804
20.0	22.4170	49.42	9.071
30.0	33.6256	74.15	13.607
40.0	44.8342	98.84	18.143
50.0	56.0428	123.55	22.679
60.0	67.2514	148.26	27.215
70.0	78.4600	172.97	31.751
80.0	89.6686	197.68	36.287
90.0	100.8772	222.39	40.823
100.0	112.0858	247.10	45.359

[Source: Neal (1974, used with permission).]

[Table 15]

TABLE 28. Pounds per gallon converted to grams per liter, pounds per liter, and grams per gallon

Pounds per gallon U.S.	Grams per liter	Pounds per liter	Grams per gallon U.S.
0.1	11.98	.03	45.36
0.2	23.97	.05	90.72
0.25	29.96	.07	113.40
0.3	35.95	.08	136.08
0.4	47.93	.11	181.44
0.5	59.91	.13	226.80
0.6	71.90	.16	272.16
0.7	83.80	.18	317.52
0.75	89.87	.20	340.20
0.8	95.86	.21	362.87
0.9	107.85	.24	408.23
1.0	119.83	.26	453.59
2.0	239.65	.53	907.20
3.0	359.48	.79	1,360.79
4.0	479.31	1.07	1,814.38
5.0	599.14	1.32	2,267.97
6.0	718.97	1.58	2,721.56
7.0	838.80	1.85	3,175.15
8.0	958.63	2.11	3,628.74
9.0	1,078.46	2.38	4,082.33
10.0	1,198.29	2.64	4,535.92

[Source: Neal (1974, used with permission).]

[Table 16]

TABLE 29. Gallons per acre converted to liters per hectare, gallons per hectare, liters per acre, and milliliters per square meter

Gallons U.S. per acre	Liters per hectare	Gallons U.S. per hectare	Liters per acre	Milliliters per square meter
.1	.935	.247	.379	.0935
.25	2.338	.618	.946	.234
.50	4.677	1.236	1.893	.468
.75	7.015	1.853	2.839	.702
1.0	9.354	2.471	3.785	.935
2.0	18.707	4.942	7.571	1.871
3.0	28.061	7.413	11.356	2.806
4.0	37.415	9.884	15.141	3.742
5.0	46.769	12.355	18.927	4.677
6.0	56.122	14.826	22.712	5.612
7.0	65.476	17.297	26.497	6.548
8.0	74.829	19.768	30.282	7.483
9.0	84.183	22.239	34.068	8.418
10.0	93.536	24.710	37.853	9.354
15.0	140.305	37.066	56.780	14.030
20.0	187.073	49.421	75.706	18.707
30.0	280.609	74.131	113.559	28.061
40.0	374.146	98.842	151.412	37.415
50.0	467.682	123.552	189.265	46.768
60.0	561.219	148.263	227.118	56.122
70.0	656.755	172.973	264.971	65.475
80.0	748.291	197.684	302.824	74.829
90.0	841.828	222.394	340.677	84.183
100.0	935.364	247.104	378.530	93.536

[Source: Neal (1974, used with permission).]

[Table 17]

TABLE 30. Square meters converted to square yards, square feet, and square inches

Square meters	Square yards	Square feet	Square inches
.1	.1196	1.076	155.0
.25	.2990	2.691	387.5
.50	.5980	5.382	775.0
.75	.8970	8.073	1,162.5
1.0	1.196	10.76	1,550.0
2.0	2.392	21.53	3,100.0
3.0	3.588	32.29	4,650.0
4.0	4.784	43.06	6,200.0
5.0	5.980	53.82	7,750.0
6.0	7.176	64.58	9,300.0
7.0	8.372	75.35	10,850.0
8.0	9.568	86.11	12,400.0
9.0	10.764	96.88	13,950.0
10.0	11.960	107.64	15,500.0
15.0	17.940	161.46	24,000.0
20.0	23.920	215.27	31,000.0
30.0	35.880	322.91	46,499.9
40.0	47.840	430.55	61,999.9
50.0	59.800	538.19	77,499.8
60.0	71.760	645.83	92,999.8
70.0	83.720	753.47	108,499.8
80.0	95.680	861.11	123,999.8
90.0	107.640	968.75	139,499.7
100.0	119.600	1,076.39	154,999.69

[Source: Neal (1974, used with permission).]

TABLE 31. Fluid ounces per 100 square feet converted to metric aliquots, gallons per acre, and liters per hectare

Fluid ounces per 100 square feet	Milliliters per 100 square feet	Milliliters per square decameter	Gallons U.S. per acre	Liters per hectare
.1	2.957	31.832	.340	3.183
.25	7.393	79.581	.850	7.957
.50	14.787	159.162	1.702	15.916
.75	22.180	238.743	2.552	23.874
1.0	29.573	318.324	3.403	31.832
2.0	59.147	636.649	6.806	63.663
3.0	88.720	954.973	10.209	95.495
4.0	118.294	1,273.297	13.613	127.327
5.0	147.867	1,591.621	17.016	159.158
6.0	177.440	1,909.945	20.419	190.990
7.0	207.014	2,228.270	23.822	222.821
8.0	236.587	2,546.594	27.225	254.653
9.0	266.161	2,864.918	30.628	286.485
10.0	295.734	3,183.242	34.031	318.316
15.0	443.601	4,774.864	51.047	477.474
20.0	591.468	6,366.485	68.063	636.632
30.0	887.202	9,549.727	102.094	954.948
40.0	1,182.936	12,732.969	136.125	1,273.265
50.0	1,478.670	15,916.212	170.156	1,591.581
60.0	1,774.404	19,099.454	204.188	1,909.897
70.0	2,070.138	22,282.219	238.219	2,228.213
80.0	2,365.872	25,465.939	272.250	2,546.529
90.0	2,661.606	28,649.181	306.281	2,864.845
100.0	2,957.340	31,832.423	340.313	3,183.162

[Source: Neal (1974, used with permission).]

Table 21--*Settling rates of airborne particles with a specific gravity of 1, in still air*[1/]

Diameter of particles	Velocity of settling	Time required to fall 50 feet
Micrometers	Feet per minute	Minutes
0.1	0.00016	312,500
.2	.00036	138,888
.4	.0013	38,461
.6	.002	25,000
.8	.005	10,000
1.0	.007	7,142
2.0	.024	2,083
4.0	.095	526
6.0	.21	238
8.0	.38	131
10	.59	84
20	2.4	21
40	9.5	5
60	21.3	2
80	33.0	--
100	47.0	--
200	138.0	--
400	354.0	--

[1/] Falling angle is assumed to be the same for all particle sizes.

Table 22--*Distance that a 100-micrometer droplet with a specific gravity of 1 will drift parallel to the ground while falling 50 feet in air*

Miles per hour	Feet
0.25	22
.5	45
1	87
2	175
3	265
4	348
5	435
10	765

Table 23--*Aircraft calibration table, speed, acres per minute, and swath width*[1/]

(Acres per minute = $\frac{\text{2x swath width x miles per hour}}{1{,}000}$)

Speed	30-foot swath	35-foot swath	40-foot swath	45-foot swath	50-foot swath	75-foot swath	100-foot swath	200-foot swath	300-foot swath	500-foot swath
m/h										
75	4.5	5.2	6.0	6.7	7.5	11.2	15.0	30.0	45.0	75.0
80	4.8	5.6	6.4	7.2	8.0	12.0	16.0	32.0	48.0	80.0
85	5.1	5.9	6.8	7.6	8.5	12.7	17.0	34.0	51.0	85.0
90	5.4	6.3	7.2	8.1	9.0	13.5	18.0	36.0	54.0	90.0
95	5.7	6.6	7.6	8.5	9.5	14.2	19.0	38.0	57.0	95.0
100	6.0	7.0	8.0	9.0	10.0	15.0	20.0	40.0	60.0	100.0
110	6.6	7.7	8.8	9.9	11.0	16.5	22.0	44.0	66.0	110.0
120	7.2	8.4	9.6	10.8	12.0	18.0	24.0	48.0	72.0	120.0
130	7.8	9.1	10.4	11.7	13.0	19.5	26.0	52.0	78.0	130.0
140	8.4	9.8	11.2	12.6	14.0	21.0	28.0	56.0	84.0	140.0
150	9.0	10.5	12.0	13.5	15.0	22.5	30.0	60.0	90.0	150.0

[1/] This table shows the rate, in acres per minute, at which spray or dry material can be applied when swath width and speed of aircraft are known. For swath widths or aircraft speeds other than those shown, interpolate or use combinations of the figures shown. To find the rate of flow in gallons per minute or pounds per minute, multiply the acres per minute figure by the number of gallons or pounds per acre to be applied.

Table 24--*Aircraft calibration computation of acreage and materials*[1/]

$$\left(\text{Acres covered} = \frac{\text{Length of swath in miles} \times \text{width of swath in feet}}{8.25}\right)$$

Swath length	30-foot swath	35-foot swath	40-foot swath	45-foot swath	50-foot swath	75-foot swath	100-foot swath	200-foot swath	300-foot swath	500-foot swath
Miles										
1/4	0.9	1.1	1.2	1.4	1.5	2.3	3.0	6.1	9.1	15.2
1/2	1.8	2.1	2.4	2.7	3.0	4.5	6.1	12.1	18.2	30.3
3/4	2.7	3.2	3.6	4.1	4.6	6.8	9.1	18.2	27.3	45.4
1	3.6	4.2	4.8	5.5	6.1	9.1	12.1	24.2	36.4	60.6
2	7.2	8.4	9.8	10.9	12.1	18.2	24.2	48.5	72.7	121.2
3	10.8	12.6	14.5	16.4	18.2	27.3	36.4	72.7	109.1	181.8
4	14.4	16.8	19.4	21.8	24.2	36.4	48.5	97.0	145.4	242.4
5	18.0	21.0	24.2	27.3	30.3	45.5	60.6	121.1	181.8	303.0

[1/] Example of how to determine the number of acres in a swath of given width and length. An aircraft with a 40-foot effective swath treats a strip 1 mile long. To find the number of acres, follow the 40-foot vertical column down until it intersects the 1-mile line. The answer to the nearest tenth is 4.8 acres. For swath widths other than those shown, interpolate or use combinations of the figures shown.

To determine the amount of pesticide required, multiply the acres by the desired rate of application.

SAMPLE FORMS FOR SPRAY DEPOSIT SAMPLING AND ASSESSMENT

FIELD REPORT

SPRAY AIRCRAFT CALIBRATION AND CHARACTERIZATION

DATE:
AIRCRAFT:
REGISTRATION NO:
PILOT:
LOCATION:

REMARKS

CALIBRATION

DATE:
TIME:
NOZZLE NOMENCLATURE:
NOZZLE REPLACEMENT:
NOZZLE NUMBER:
NOZZLE POSITIONING:
NOZZLE SPACING:
BOOM PRESSURE:
TYPE CALIBRATION:
SWATH WIDTH:
SPRAY MATERIAL:
APPLICATION RATE:

DIAGRAM OF GRID

CHARACTERIZATION

DATE:
TIME:
LOCATION:
RELEASE HEIGHT:
AIRCRAFT SPEED:
BOOM PRESSURE:
SPRAY MATERIAL:
APPLICATION RATE:
GRID DESIGN:
DEPOSIT CARD SPACING:
INWIND OR CROSSWIND:
RELEASE POINT:
LENGTH RELEASE:
WIND SPEED:
WIND DIRECTION:
RELATIVE HUMIDITY:
TEMPERATURE:
INVERSION, NEUTRAL, LAPSE:
DROPS PER CM^2:
DROP SPREAD FACTOR:
VOLUME MEDIAN DIAMETER:

WORK SHEET FOR FIELD SPECTRAL COUNTING

SPECTRAL COUNTS

Test:_____ STAIN SIZE (μm) Date:_____

Card No.	<400	<800	<1200	<1600	<2000	<2400	<2800	<3200	<3600	<4000	<4400	<4800	<5200	<5600	<6000	<6000	Total drops/cm^2
129																	

TRIAL LOG FORM

Trial Number _____ Time/Date _____ Time Zone _____

Row _____ Row Azimuth _____ ^{o} Card Separation _____ m

Number of Cards _____

I. SPRAY SYSTEM DATA

Aircraft _____

Spray Nozzle _____ Nozzle Orientation _____

Airspeed _____ (mph) Flow Rate _____ gallons min^{-1}

Flight Altitude ____ (ft or m) Aircraft Heading _____ ^{o}

Spray Material _____ Material Density _____ g cm^{-3}

Stain Factor Formula _____

Stain Factor Constants _____ _____ _____

II. METEOROLOGICAL DATA

Cloud Cover _____ % Temperature _____ ^{o}C

2-m Wind Direction _____ ^{o} 2-m Wind Speed _____ m sec^{-1}

Relative Humidity _____ %

(Optional Measurements Using Pilot Balloons and/or Tethersonde)

Wind Profile

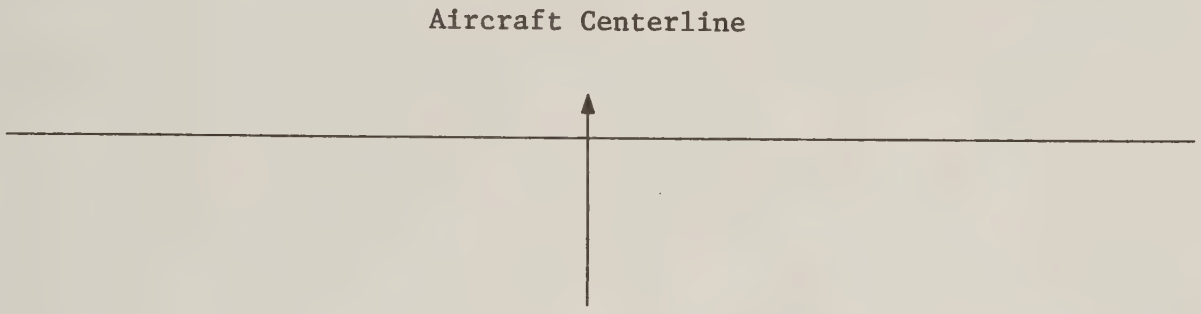
Height (m)	Direction (^{o})	Speed (m sec^{-1})

Temperature Profile

Height (m)	Temperature (^{o}C)

TRIAL LOG (Continued)

III. NOZZLE CONFIGURATION



IV. REMARKS

DATA FORM FOR

FIELD ESTIMATE OF SWATH WIDTH AND DROPLET DENSITIES

Date _____
Trial Number _____
Row/Line Number _____

Card	Area (cm^2)	No. of stains	Density ($drops\ cm^{-2}$)
_____			
_____			
_____			
_____			
_____			
_____			
_____			
_____			

Card Number for Left End of Swath _____

Right End of Swath _____

Estimated Swath Width _____

DATA FORM FOR
VOLUME MEDIAN DIAMETER (VMD) ESTIMATES

Trial Number _____ Spray Material _____

Time/Date _____ Stain Factors a _____

Row/Line Number _____ b _____

Aircraft _____ c _____

Aircraft Altitude _____ Flow Rate _____

Aircraft Speed _____ Miscellaneous _____

_____

_____

Largest Stains and Drops

Card Number	Stain Diameter	Drop Diameter

Five Largest Drops

Card Number	Drop Diameter

$$VMD = \begin{cases} DD/2.2 & (80\text{-}120 \text{ mph}) \\ DD/2.5 & (> 120 \text{ mph}) \end{cases}$$

VMD = _____

DATA FORM FOR

DROP DENSITY AND MASS DEPOSIT DATA

Trial Number _____ Mass Mean Diameter _____(μm)

Row Number _____ Mass _____(mg)

Conversion Factor: 1 oz. $acre^{-1}$ = 1.427 x 10^3 mg cm^{-2}

Card Number	Template Area (cm^2)	Stain Count	Drop Density ($drops\ cm^{-2}$)	Deposition	
				($mg\ cm^{-2}$)	($oz.\ acre^{-1}$)
Total					

Mass Recovery _____($mg\ m^{-1}$)

Deposition Efficiency _____(percent)

METEOROLOGICAL DATA FORM

Plot _____ Date _____

Observer _____

Time of Application: From _____ To _____

Time	Temp.	R H, %	Wind		Remarks
			MPH	Direction	

Sky: Clear _____ Cloudy _____ Fog _____ Rain _____

Foliage: Dry _____ Moist _____ Dripping _____

Comments on weather, or spray behavior: